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Ogden
Utah

From N. A. Lockwood Chief Engineer, '08-'29
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BEET-SUGAR MANUFACTURE

BY

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AUTHORIZED TRANSLATION FROM THE
THIRD GERMAN EDITION

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SECOND EDITION
FIRST THOUSAND

NEW YORK
JOHN WILEY & SONS
London: CHAPMAN & HALL, Limited
1910

THE SCIENTIFIC PRESS
ROBERT DRUMMOND AND COMPANY
BROOKLYN, N. Y.

PREFACE.

THE aim of this book is to refresh the memory of technical sugar men on the more important things observed in the conduct of a sugar-factory; it may serve, furthermore, as a guide for beginners in practical sugar-work, and as a basis for further studies.

It is in no way intended that the book will replace any of the text-books or handbooks that treat of the manufacture of beet-sugar; in fact it is assumed that the reader already has a general knowledge of sugar-chemistry and sugar-technique. In such books, however, that which is of utmost importance to the practical sugar man, namely, the theoretical principles upon which the methods of working depend and the many rules, tricks, and numerous other little things learned by experience which are so necessary for the proper conduct of a sugar-factory, is either incompletely treated or vaguely distributed throughout the other subject-matter. Most practical sugar men, therefore, will find but little that is new in these pages, but it cannot be distasteful to them to have the matter briefly summarized so that they can look it over during the long pause between two campaigns.

A book concerning the sugar-industry can be written only by one who has himself had practical experience. Consequently the author will be pardoned and not considered narrow-minded for having stated in many cases merely his own experience; at all events he has tried to make his treatment of the subject as objective as possible and with reference to the experience of others in so far as he has learned it from personal contact and from the literature. Most of the original articles which have been used

are referred to in the back of the book, so that the reader himself can look further into questions which he finds are not treated fully enough, and also form an independent judgment.

H. Claassen, Ph.D.

Dormagen, April, 1901.

NOTE TO THE SECOND EDITION.

The book has been improved by additions and changes without affecting the brevity and comprehensiveness of the treatment.

Dr. H. Claassen.

Dormagen, November, 1903.

NOTE TO THE THIRD EDITION.

As in the second edition, the author has made additions and changes without altering the general plan of the work. The sections on Juice Extraction, Drying the Spent Chips, and Crystallization, as well as the calculation on the Steam Consumption in the Appendix, have been worked over, and in all other chapters of the book the text has been revised and made clearer.

Dr. H. Claassen.

Dormagen, January, 1908.

TRANSLATORS' PREFACE.

Claassen's "Zuckerfabrikation" is already familiar to most well-informed sugar men. It has taken high rank in the literature for its concise and intelligent presentation of the vital points of process detail and as a guide for manufacturers of some experience. Much that has been treated by Claassen can be applied to the cane-sugar industry as well, so that cane-sugar experts have learned already to value the work as one of great usefulness when the text is applied with proper discrimination as to fundamental differences in process.

The translators offer an English text giving data of factory practice in those units in every-day use in our own sugar houses in the belief that such will be welcome to many.

W. T. H.
G. W. R.

September, 1906.

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BEET-SUGAR MANUFACTURE.

INTRODUCTION.

The first and most important factor of success in beet-sugar manufacture is a properly cultivated beet rich in sugar. Therefore the sugar manufacturer should use all the means in his power to persuade farmers to cultivate the beets so that not only the harvest will prove of satisfactory weight, but the beet-juice will be pure and of high sugar percentage. The most certain means of accomplishing this is to purchase the beets not merely by weight but according to the amount of sugar that they contain, although this may not always be possible. In the latter case the manufacturer must content himself with furnishing contracting farmers with seed which has been properly bred and prescribing the method of fertilizing and tillage.

A rich sugar-beet which gives a pure juice is not only absolutely but proportionally more valuable than a beet which gives an impure juice or than a beet poor in sugar; for with these latter there is a greater loss in sugar in manufacture, while the cost of working is at least as great for the same weight of beets. Hence, in comparison with the sugar yield, the cost is greater, aside from the additional consideration that the expense is frequently increased by the slower process.*

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* Further, the capacity of the house is considerably diminished in working beets of low purity, owing to the increased amount of after-product. —Translators.

The sugar-content and the purity of beets and juice not only depend upon conditions which man can control, but also upon the weather, the climate, and the nature of the soil. Where the climate permits, the harvesting of the beets should be delayed as long as the approaching frost permits; for the longer the growth period, the more sugar there will be in the beet, the purer the beet-juice, and the heavier the beet-yield.

All of these points, important as they are, are of more concern to the farmer than to the sugar-manufacturer. The activity of the latter begins at the time the beets are delivered at the factory.

CHAPTER I.

THE DELIVERY, RECEIVING, AND STORAGE OF BEETS.

THE time for *opening the campaign* depends not only upon the ripeness of the beets but also upon the amount at the disposal of the factory and upon its capacity. If a large quantity of beets are to be worked up so that a long campaign is expected, it is advisable to begin as soon as possible, say by the first or middle of September, or as soon as the sugar-content of the beets makes it profitable. In order to have the necessary data for deciding this question it is highly desirable to have a number of samples taken from the fields and tested by the end of August.

If the factory expects only a small beet-harvest, the opening of the campaign should be delayed as much as possible so that from the first week there will be ripe beets on hand, and throughout the whole campaign only freshly-harvested, ripe beets will be worked up. In short, each year the work must be planned for the largest possible average sugar-yield; if the work is begun too early, the factory suffers by having beets which are unripe and consequently deficient in sugar; while, on the other hand, if begun too late, the loss in sugar will be considerable on account of the prolonged storage of the beets.

In southern countries, where sugar-beet culture has been established for some time, other factors must be taken into consideration in beginning and ending the campaign. There the beets ripen very quickly in summer and must be worked up as quickly as possible before the rainy season of the autumn causes a renewed growth and consequent loss of sugar. This and other peculiar conditions caused by the climate must be taken into consideration if

the maximum average yield is to be obtained from the beets. On the other hand, in countries where continued frost comes early the case is quite different. In such places the campaign must be begun early enough to allow the farmer sufficient time to harvest all of his beets.

A regulated delivery of beets is of great advantage to the manufacturer, so that sometimes contracts with the farmers prescribe how many beets shall be delivered each week and even how many daily. All factories, however, are not in a position to enforce such a condition, for the farmer who cultivates beets often suffers great hardships and disturbances in his industry. Therefore most factories require only a certain regularity in the delivery of the beets, while others make no requirements with regard to delivery, but are compelled to accept the beets when the farmer chooses to deliver them.

Provisions for receiving and keeping the beets must be made according to these different conditions. When the delivery is strictly prescribed it is unnecessary to provide space for receiving a large number of beets; place for a few days' supply is sufficient. When the delivery cannot be so systematic the receiving bins must have greater capacity. On the contrary, where the beet-delivery is quite unregulated small bins usually suffice, for during the harvest period there are sure to be too many beets delivered, and this excess must be stored or *siloed.*

It is often injurious to have too large a place for receiving the beets, especially when they are piled in large heaps over hydraulic carriers fed with warm water; for the beets kept in this way for days or even weeks, and warmed by the vapor rising from the warm water, become so damaged that they are worked up with difficulty and yield a dark-colored juice of diminished sugar-content.

The bins, sheds, or so-called beet-cellars, are either above or below ground, and may have roofs or be uncovered.

Beet-cellars are without doubt the most practical places for

receiving the beets, as these can then be unloaded and placed in the hydraulic carrier without the expenditure of much time or labor. It makes no difference with regard to keeping beets whether the cellar is covered with a roof or not, as usually they are to remain there but a short time; consequently roofs when built are merely to protect the workmen or draft-cattle from the weather. When beets are delivered by rail, the side walls of the cellar should not be higher than the bottoms of the cars, so that the doors can be kept open no matter how they are arranged, and the workmen can unload without difficulty. In railroad delivery it is very convenient to build bins with side walls of old wooden sleepers set on end, the hydraulic carrier being at the bottom in the middle, and the railroad tracks on both sides.

The breadth of the bins must be regulated by the difference in the height of the upper edge of the side wall and the water level in the carrier, so that the bottom can be built sufficiently inclined for the beets to slide into the carrier. If, when the covering is removed, the beets do not slide into the hydraulic carrier by themselves, or with little help, considerably more labor will be required. Such constructions are unpractical and increase factory expenses.

The cellars should be located where the railroad cars can reach them easily and quickly, and so situated that turntables can be avoided, and the tracks so arranged that full cars coming in will not interfere with the departure of the empty ones. Beets are almost invariably unloaded with forks. The ever-increasing cost of suitable labor for this work, disagreeable as it is when beets are dirty, seems to make **mechanical unloading** advisable. As the present types of railway cars have to be used, all that is necessary are tipping devices moved by hydraulic power. Many of these machines in present use in factories are rather costly and do not meet all requirements. A good dumping machine ought to unload beets quickly and directly into the canals without any manual labor. Nets are also recommended for discharging beets, large enough to take up the whole load out of the car at once.

A very important matter to be attended to at the time the

beets are delivered is the **determination of the adhering soil.** Sometimes the amount of dirt is simply estimated, but it is preferable to make a direct determination, and in this case sample-taking is an important operation. The best method is to take out, by means of the beet-fork, in a definitely prescribed way, 50 or 100 pounds of beets from each car, and then determine by scraping, brushing, or washing the amount of adhering soil as well as the weight of the heads which are cut off. As it is impossible to expect to obtain an absolutely correct average determination by taking a sample for analysis, which represents only about $\frac{1}{4}$ of one per cent. of the total car-load, it is not strange that such determinations sometimes lead to unpleasant disputes between the factory and the farmer. In order to avoid these misunderstandings as much as possible, it is well to have the sampling carefully checked by the seller or his representative. If the determination of the soil is made by washing, a deduction of one or two per cent. should be made for the amount of moisture adhering to the washed beets. The *heads* should be cut off squarely under the leaf-base and not pared off. If the beets have large, green or empty heads, it seems but fair to cut below the base of the leaves, as such beets have not been cultivated with the prescribed care, and the green part of the beets as well as its hollow head is deficient in sugar and gives an impure juice. Special deductions should also be made, in all fairness, for frozen, rotten, or otherwise injured beets, so far as their condition is the fault of the contractor.

Injuries which the beets undergo in the transportation to the factory are usually borne by the manufacturer. It is important to avoid such injuries as much as possible and to handle these injured beets so that the injury is not made worse. The most disagreeable foe to be contended with in the transportation of the beets is the sudden appearance of a heavy frost which not only freezes the beets but makes it difficult to unload them, as they stick together in a hard lump. Frozen beets must be worked up at once, for they decay very quickly as soon as they become thawed out. Sugar-beets can stand a temperature of about 30° F. (– 1° C.)

without freezing. At lower temperatures they are **frost-bitten,** but not thoroughly frozen until the life of the plant-cells has been killed by the action of the frost. Beets which are still in the ground and covered by their own foliage can stand quite a heavy frost without suffering, being at most but slightly injured by a long period of frost, provided they are allowed to remain in the ground until they have completely thawed out again.

At the same time it is necessary that such beets should be used immediately after they are pulled. Experience has shown that rich sugar-beets, which usually have a firmer tissue, are less affected by cold than beets containing less sugar and with softer pulp. When beets are transported in barges, the latter should be as shallow as possible, and not decked over, and the beets should remain in the barges as short a time as possible, because they tend to become heated and are then harder to work, yielding a dark juice.

The Storage of Beets at the Factory.—Beets which cannot be used immediately after their delivery must be *stored* or placed in heaps or silos. The choice of a proper method of storage is important, in order that the beets shall lose the least sugar and the work of storing and taking them away be with the least cost; in short, the whole arrangement should involve as little expense as possible.

During the time of storage there is bound to be a certain amount of sugar lost by the beets, for the beets respire as long as they are healthy, and the sugar stored up in them is used up by this respiration.

The strength of the **respiration** depends upon the temperature and the nature of the beets. For a normal respiration access of air is necessary. It would be erroneous, however, to think that respiration, and consequently the loss of sugar in beets, could be avoided by limiting the supply of air; metabolism takes place in the beets even when they do not take up oxygen from the air. Anaërobic metabolism then occurs by which the sugar is converted into alcohol and carbon dioxide.

The sugar-content of beets has no influence upon the strength of respiration, but it does affect the amount of active protein;

the respiration, and hence the sugar-loss depends accordingly upon the condition of the individual beet and, in general, is greater in unripe beets than in ripe ones. The result of this respiration is the conversion of the sugar into carbon dioxide for the most part, but other organic substances are formed to some extent and remain in the beet-juice.

The chief requirement for keeping beets well in storage is that they should not be pulled from the ground too early, at all events not before the middle of October, and that they should be stored fresh and uninjured while the weather is as cool as possible without being frosty.

Beets seem to keep best in small heaps covered with earth; consequently those kept for seed are stored in this way. This method is not employed for storing beets at the factory, because it requires altogether too much space and is too expensive.

In countries with a mild climate **large heaps** which are uncovered are to be preferred to all other methods of storage, because the amount of sugar lost is very small and the storage requires but little space and the expenditure of but little labor. As beets are not injured by temperatures slightly below 32° F., when they are left undisturbed and are allowed subsequently to thaw out slowly, only those lying directly on the outside of the heaps are likely to be injured by a short period of frost, and these only when a heavy frost and sudden thaw follow one another closely. Within the heaps the cold penetrates but slowly, even when quite severe, and beets when once frozen thaw out very slowly, so that as a rule they are taken out in an undamaged condition. Only those beets which are actually killed by frost are lost by thawing, for such immediately begin to decay. In countries where the climate is generally mild, loss on account of frozen beets is so slight as to be of no consequence compared with the good preservation of the whole by the low and regular temperature in the heaps.

It is essential, however, that the surface of the heap should be as even as possible. In proportion to its contents there is less surface exposed in a smoothly trimmed heap than in one which is not, and consequently the former suffers less from exposure to the

weather. Another disadvantage which the uneven heaps possess is that the sharp corners act as chimneys and help to remove heat and moisture. Consequently the beets in these little elevations are warmer and moister than the others and experience more aftergrowth. When the frost comes, the peculiar phenomenon will be noticed that the beets in the highest portions do not freeze first, but those in the little hollows of the surface, because here the cold air is sucked in.

It is frequently recommended that the beet heaps be covered over with a roof. Beets kept in this way show a little higher sugar-content than those which are left uncovered, but they decrease more in weight, so that the actual loss in sugar is not very different. In countries where beets are taxed upon their weight it may be advisable to build the roof, and there is also an advantage to be gained in having the ground thus always kept dry and hard, which facilitates the piling of the beets and cartage back and forth. In case there is no tax placed upon the beets, the cost of building roofs and keeping them in repair will not be covered by the increased yield of sugar. In localities where severe and early frosts prevail it is necessary that the heaps should be covered. As this often has disadvantages and involves considerable expense, it is a common practice in such places to place the beets in **large pits,** or else dig large **beet-cellars,** which are but slightly ventilated. These cellars have proved very useful in cases where the beets are placed in them dry with but little soil adhering and are not stored too long.

The greatest foe of stored beets is heat, particularly moist heat. In southern countries, therefore, where the climate remains warm throughout the sugar-making period, it is evident that storage of the beets should be avoided as much as possible. But even in localities where the temperature is moderate or even cold, it is possible for the beets to become heated more or less strongly, by the heat of respiration, at places in the heaps or store-houses where the movement of the air is restricted so that they are not cooled off. This trouble occurs when there are large quantities of adhering dirt and when many leaves and weeds are

stored with the beets. Those places become most heated where the beets fall as they are thrown in, and where the dirt collects and forms a mass with the weeds which adheres to the beets. It is advisable, therefore, to watch the temperature by inserting thermometers. As soon as the heating becomes permanent, the beets affected should be worked up immediately, if possible.

No matter how the beets are stored, they are certain to suffer more or less **change in weight,** usually a loss. Only those which are affected by rain, dampness from the earth, or by water evaporating from the beets at the bottom of the heap, increase in weight; and this is noticed in particular when they have been pulled and transported in dry weather. In all other cases beets decrease in weight. This loss in weight is greater in proportion to the wetness of the weather during the time of harvesting and storing, to the completeness of the removal of the atmospheric moisture, to the warmth within the heaps, and to the extent to which they are ventilated.

The loss in weight is greatest in cellars or heaps which are ventilated and roofed over, and amounts to from 5 to 10 per cent. of the original weight. In uncovered heaps which are not artificially ventilated there is either no noticeable change in weight owing to the action of the weather, or there may be even a slight increase in weight. In large heaps covered over with earth there is always a loss amounting to about five per cent.

The **sugar-loss** which the stored beets undergo is greater the higher the temperature, the greater the humidity changes, and the more the ventilation. In determining the loss of sugar during storage, it is absolutely necessary to take into consideration the change in weight which the beets have undergone, or the conclusion drawn may be misleading. The actual sugar loss in a mild climate with an average temperature of about 40° F. during storage from the end of October to December amounts per day to 0.010 to 0.012 per cent. in large uncovered heaps, 0.012 to 0.017 per cent. in ventilated heaps, and 0.019 per cent. in large heaps covered with earth.

The figures given above were obtained from observations

made with uninjured beets. **Injured beets** from which the tails have been broken off or which have been headed too much, and in particular those beets which have been wounded by the prongs of the fork or by the knife, will show a much greater sugar loss. They also suffer much more from the influence of mould and diseases caused by *phoma*, *rhizoctonia,* and *sclerotinia,* which sometimes ravage stored beets. At the infected places, the flesh of the beet becomes black, and the rotting penetrates, in a short time, deep into the interior; so that the beets become rotten within a few weeks. Fresh beets harvested from moist soil usually prove more resistant than beets which have become wilted by prolonged drought on the field before harvesting. In the last case nearly all of the beets are considerably injured on account of the difficulty in pulling them out of the ground; and, therefore, doubly damaged.

If the beets grow during the time of storage, it is always a sign that they were laid away when too warm and too moist. The formation of **sprouts,** therefore, is to be traced to an increased life-activity, which is naturally connected with a stronger respiration, with a greater change in substance, and a greater loss in sugar. In the sprouting itself there is only a slight sugar loss, for these offshoots weigh but little compared to the whole beet, even when they have been formed to a considerable extent, and the sugar which they contain amounts to only three or four per cent. (sugar and invert-sugar).

The **temperature** of the stored beets depends chiefly upon that of the outer air. Every lasting change in the temperature of the atmosphere makes itself felt within the heap and cellars, naturally the change taking place more quickly in the uncovered heaps than in those which are covered, and most quickly in places exposed to the weather.

Inasmuch as heat is evolved by the respiration of the beets, it follows that the temperature within the piles of beets is greater than the average outside temperature; this difference in temperature of course depends largely upon the amount of ventilation.

During the storage of beets there is an increase in the amount of organic non-saccharine matter present in the juice; because sugar is decomposed most, and furthermore certain insoluble portions of the beet are transformed into soluble non-saccharine matter which cannot be removed by the processes of sugar-making.

CHAPTER II.

TRANSPORTING AND WASHING THE BEETS.

Conveyance of Beets from Storage to the Factory.—Formerly beets were transferred from the places where they were deposited to the washing-machines by means of a cable system, wheel-barrows, or by baskets, but at present the practice of using a **hydraulic carrier** has become almost universal. As has already been mentioned, this carrier is placed in the middle of the storage-place, so that by means of properly arranged inclined planes the beets are dropped into the stream of water with the expenditure of but little manual labor. These inclined planes are built either solid or as a grating. In the latter case, a good deal of the dry dirt which adhered to the beets in the form of soil tends to drop through on to the ground beneath, so that the hydraulic carrier will contain less dirt, and less of it will reach the settling-tank. This latticed platform is only advantageous, however, when the settling-tank is small, and when the dirt can be readily removed from beneath the latticework. In wet weather, moreover, the mud adheres firmly to the beets and stops up the spaces between the grating, so that when the beets are the dirtiest, all of the dirt will be transferred to the carrier; consequently these latticed platforms can usually be dispensed with.

The hydraulic carriers are usually laid at the place where they are to be used, and are as a rule made of brick or concrete, smoothly finished on the inside, although gutters of cement or iron are used to some extent, particularly the last when the carrier is movable. Its vertical or inclined walls are at least 20 to 25 inches high, the bottom is rounded, and the width is from one to two feet according

to the amount of beets to be handled. There is a groove on its upper edge in which is placed a covering for the channel made of wood, sheet iron, or iron grating. With regard to the fall which the water in the stream should have, it is impossible to prescribe this for all cases. As a rule, the water should have a fall of from 0.1 to 0.15 inch per foot in the straight portions and from 0.15 to 0.20 inch at the curves. The dirtier the beets, the more sharp sand and stones this dirt contains, the more sprouts the beets have, and the more careless the farmer has been in removing the leaves and weeds, the greater the waterfall and amount of water which will be necessary.

In order that the carrier may work well, especially when it is a long one, it is necessary that the beets should be pitched into the stream at one place, and that the flow of water should not be stopped during the passage of the beets. If the water at the outlet cannot run off freely, it is necessary that the siphon arrangement should be capable of taking away the water, even although intermittently, so quickly that the water in the channel does not become dammed up. Every time the stream of water becomes dammed there is a stoppage of beets as well as stones and sand, and some time elapses before the carrier acts normally again.

The **water-supply** required to operate the carrier depends in the first place upon the quantity of beets which it is to carry. Less than 70 to 100 cubic feet per minute should never be allowed. Ordinary factories usually use from 140 to 175 cubic feet per minute; larger factories use more correspondingly, especially when there are two carriers. More water will be used, however, in proportion as the stream is wide and the fall of the water is slight. If the supply of water at the factory is limited, therefore, it is particularly important that the width of the stream and the waterfall should be carefully regulated. The water used in the carrier is usually from the hot wells of the condensers. If this water is to be used again for factory purposes after it has cooled, it is necessary that it should stand some time in a settling-tank, in order to remove most of the dirt taken up from the beets.

During the time, whether long or short, that the beets are in

the warm water there is bound to be a certain amount of **sugar lost,** although this loss is usually very small. As an average of a great many experiments, it has been found that for 100 parts by weight of beets carried by water through a channel about 240 yards long the loss in sugar will be:

with sound beets and warm water (105°–115° F.), (40°–45° C.),
0.02% to 0.03%, on an average; at the most, 0.05%;
with frozen and injured beets and warm water,
0.1% to 0.57%, varying according to the amount of frozen and injured beets present.

Under ordinary conditions, therefore, the loss in sugar is but slight, and will not be noticeably lessened by making the carrier shorter or using colder water. On the other hand, the amount of sugar dissolved out of frozen beets depends to a considerable extent upon the length of the carrier and the temperature of the water. But since it is very difficult to float muddy beets which are frozen together by means of cold water, warm water being required to thaw them and loosen the dirt before they can be transported in the carrier, it is evident that the loss of sugar must be regarded as unavoidable. Consequently the use of cold water, which has been sometimes recommended, is unnecessary in the case of uninjured beets and useless in the case of frozen ones.

During the time that the beets remain in the water, both in their transport to the factory and their washing, they take up a certain amount of water and gain in weight, and of course this gain is more noticeable in the case of dry and withered beets than in the case of fresh ones. The increase in weight, however, rarely exceeds ½% to 1%.

A contrivance which is very desirable and which may be placed in the channel just before the outlet is the **sand and stone-eliminator.** For this purpose machines of various designs have been constructed. Stones and sand are either removed by placing a grating at the bottom of the hydraulic carrier above which the beets float by, and from beneath which the deposit is shovelled away from time to time; or they sink into a deepen-

ing in the carrier from which an upward current of water carries the beets along. There are also contrivances which remove the floating, lighter particles, such as leaves, straw, wood, and weeds, but these devices require a uniform current in the carrier and careful attention.

If the beets are not stored in cellars which are provided with hydraulic carriers, the *transportation of the stored beets* to the washing-machines is usually effected by means of a portable railway. In order to cheapen removal from the ordinary heaps and silos, it is well to make use of portable hydraulic carriers which can be moved on rollers or trucks, when the ground permits, so that the beets can be readily thrown from the heaps into the carriers.

The warm water can best be brought through open channels. Pipes are not only expensive, but stones are likely to stop them up.

Washing the Beets.—The beets after reaching the factory at once enter the washing-machines if these are at low enough levels, or are raised to them by means of suitable arrangements (buckets, lifting-wheels, screw conveyors, or chain elevators) either with or without the water.

As such apparatus becomes more or less worn from usage, it has recently been recommended to employ compressed air in a similar way as in the case of the so-called "mammoth pumps" for raising water. The contrivance consists of a wide U-shaped, bent tube of which one arm is 1.5 times as long as the other. The beets flow into the shorter arm together with water from the carrier, and the compressed air in the lower part of the longer tube makes the whole mass specifically lighter, so that it rises in accordance with the principle of communicating tubes. Water and beets flow upward into a spout and from this into the washing-machine. To prevent the tube becoming stopped up with sand when not in operation, a valve in the longer arm is then closed, the mass in the short arm is kept in motion by a small amount of compressed air.

Before entering the *washer*, the beets should be freed from

the carrier-water, in order that the dirty water shall not contaminate the clean. It is true, however, that impure water is often used for washing the beets, for example, the water which has run off from the diffusers and from the chip-presses, or filtered condenser water; but where there is a plentiful supply of pure warm water it is best to use it, as unclean water in the washer is often the cause of objectionable irregularities in the diffusion, and the beet-juice is likely to become contaminated. Invariably, under all circumstances, the beets should be finally washed off with clean water, and where the beets are washed twice, the second washer should be fed with pure water.

For **washing** it is preferable to make use of long agitated washers with places for large stone traps. Drum washers are no longer used on account of their inefficiency. Recently vertical washing-machines have been recommended, from which the beets are raised by a screw. These are claimed to possess the advantage of completely removing the stones, straw, leaves, and in fact all undesirable impurities, but up to the present time they have been but little used in practice. A special contrivance on the screw conveyor for the beets works in a similar way to this washer in removing stones. Under the conveyor at the bottom there is an elevated trough, at which point the spirals are replaced by some stirring arms. The stones fall between these arms to the bottom and are removed by a conveniently placed manhole.

Since the beets have been freed by the hydraulic carrier from the greater part of the mud which adhered to them, it is evident that the washing-machines do not have quite so much work to do as formerly. At the same time their work remains of much importance for the succeeding operations, especially in preventing the choking the teeth of knives and facilitating the preparation of good chips. Washing, therefore, serves chiefly to remove the last traces of dirt and the stones. The first is accomplished by causing the beets to collect in the front part of the washer so that they are obliged to rub up hard against one another. In the neighborhood of the stone-eliminator, however, there must

not be too many beets, or the stones will not settle so quickly. In order to accomplish these ends, the principle to follow is to have the throwing-out arrangement of the stone-eliminator, or of that part of the washer, capable of handling more beets than are brought into the washer. When so constructed, washers work satisfactorily; otherwise the results are never so good. Arrangements by means of which the lower mud-holes open and shut automatically at definite intervals, are desirable, as they make the process independent of manual labor.

The stirring arms of the washer are usually made of wood and are frequently so arranged as to partly stop the progress of the beets. They are sometimes fluted so that they rub against the beets more, or provided with finger-like side attachments which collect weeds and leaves.

CHAPTER III.

WEIGHING AND SLICING BEETS.

The beets are carried from the washing-machines by means of an elevator (bucket, chain, or link) to the collecting-bin. As beets were formerly taxed on their weight, great stress was laid on draining them as much as possible before weighing. Nowadays less attention is paid to this point; but this is not right, inasmuch as the water adhering to the beets contains a great deal of mud, sand, and bacteria. The sand tends to choke the teeth of the knife-blades and cutting-plates, and eventually passes through the diffusers into the mud-pits, which require continual cleaning. The amount of microörganisms present during the diffusion process depends on the quantity of water adhering to the beets; their activity sometimes becomes noticeable and may increase greatly.

There are numerous and various *contrivances for weighing beets.* A great many factories do not weigh the washed beets at all, but consider the weight taken at time of purchase as sufficient, making deduction for the adhering dirt, or else determine the weight from the contents of the diffusers. Both methods are thoroughly unreliable and should be discarded; for when the weight of beets is not known accurately, the first and chief requirement for the control of sugar-yield is wanting. Consequently every properly conducted factory should accurately weigh the washed beets.

As it is usually difficult to obtain trustworthy weighers, automatic weighing-machines are obviously best, and there are a number of these which are perfectly reliable. There are, however, methods of checking the weights taken by ordinary scales with the

requisite precision, so that the latter, owing to their inexpensiveness, are much in use.

The beets fall from the weighing-hopper either directly into the slicing-machine, or into a collecting-bin from which they are raised to the slicer by an elevator. Where space and height are available, the former method is preferable, for it is easier to keep the hopper over the feeding-discs full than when the beets are delivered into a less readily accessible hopper the inside of which is not visible. In order to feed the slicer regularly when an elevator is used, it has been suggested that the loading and unloading of elevator and slicer be made simultaneous by an electric controller.

Slicing the Beets. — For slicing beets into "schnitzels," or "chips," **beet-slicers** are used, based on the well-known construction of a horizontally revolving cutting-plate. Particular stress is laid upon a careful mounting of the machines so that the cutting-plate runs perfectly. There is a centrifugal slicer made on a different principle which has not come into any extended use in the industry. Recently a rotary drum slicer has been invented in which the knives are placed on the circumference of a drum which turns on a horizontal axis. The beets fall through a funnel on the side into the drum and are pressed against the knives by a horn-shaped hook. This machine has great capacity and makes very good long slices. The customary horizontal machines differ essentially only in size of cutting-discs and arrangement of hopper.

The **cutting-plate** must be made of the best cast steel and carefully finished. Its diameter in German factories is usually from four to five feet, but in other countries larger plates are often used, sometimes up to eight feet in diameter. The smaller plates make from 100 to 150 revolutions per minute, while the larger ones revolve only 50 times or less. In general, it would be assumed that the larger plates, moving slowly, would make better slices than the smaller ones, moving more quickly; the quality of the slices, however, depends upon a great many things, and it is a fact that in some cases more satisfactory slices are obtained with the smaller plates than with the larger ones. It should

also be remembered that the larger machines require more time for changing knives and removing stones which get into the machine, so that, unless extra machines are at hand, the work is likely to become irregular. It is, therefore, difficult to say what sort and size of plate is the most desirable.

The **driving** of the beet-slicers is almost always by means of belts. There are, however, machines which are provided with an independent steam or electric motor. The advantage of such machines is that the number of revolutions can be changed more readily, but, on the other hand, the cost of installation is too great to permit their general use.

Above the revolving plate is the **cover-piece,** the construction of which has an important influence upon the capacity of the machine. There are two types of cover-pieces; one is connected with a feeding-hopper so that the beets press against the cutting-disc by reason of their own weight, the other type is provided with an arrangement for exerting pressure.

In the former, the annular-shaped **feeding-hopper,** which rests upon this cover-piece, must be made so that the beets slide through it without difficulty and cover as large a portion as possible of the plate in which the knife-holders rest. In the lower part it consists of two concentric jackets, with a break only where the knife-holders are inserted. At the bottom, the breadth of this hopper is a little greater than the length of the knife-holders. It is, however, not correct to have both jackets of the hopper built too high; it is much better if the inner jacket forms only a shallow cap over the centre of the cutting-disc where the shaft-bearing is situated. This cap consists of a conical or smoothly rounded cover, usually with sloping sides. The outer jacket, on the other hand, is at least 1.5 or 2 yards in height, so that there is a good-sized hopper into which the beets fall freely and without friction to the mass below as fast as the beets at the bottom are sliced up by the knives. On the inside of the hopper or on the inner cap there should not be anything, such as nuts, bolts, or rivets, which might interfere with the fall of the beets. The unimpeded fall of the beets is more important in proportion to

the speed of the machine, the number of knife-holders, and the capacity of the machine in general.

In order to prevent the beets from turning with the plate and to keep them firmly in place so that they are properly sliced by the knife-blades, stops or counter-knives are placed in the cover-piece close to the plate, so that they come within a few millimeters of the highest part of the blades. In the case of a small plate, one such stop is sufficient.

The stops are sometimes made movable and held by steel springs or counter-weights. Stones and pieces of iron can thus push through and excessive strains, which might cause the cutting-plate to break, are avoided.

For the rapid **removal of foreign substances** which get into the beet-slicer, such as stones, pieces of iron, wood, or coke, small doors are placed in the outer jacket opposite these stops, and over these doors are a number of holes through which steel rods can be introduced. As soon as it becomes evident from a peculiar rattle inside the machine that a hard foreign substance has reached the knife-blades, the machine must be stopped at once, although often before a piece of iron or a hard stone can be removed, the knives or the plate will break. Therefore an extra cutting-plate must always be on hand. At all events, the longer the foreign substance remains, the more knives will be dulled. The obstruction will almost always be found against a stop, and it is removed through one of the above-mentioned little doors. Steel rods are introduced through the holes in order to prevent the beets from falling out, and the foreign substance is usually under the beets lying next to the stop. In case the stone cannot be found here, one of the knife-holders is removed from the plate, and the latter is caused to make one revolution backwards. This causes all the beets and pieces of beets which were upon the plate to fall out through the open door. As it requires considerable power to make this backward revolution, the machine should be fitted with an arrangement for this purpose. There are a number of such which are good.

The cover-pieces arranged to **press the beets down** consist of

one or several compartments, or channels, running in the form of a spiral over the cutting-plate. The beets are fed through a common hopper into the highest part of the channel and are carried along into the narrower part by the motion of the cutting-plate in such a way that the pressure channels are always kept filled with beets as far as the stop. The beets are thus arranged in a perfectly fixed position against the knives and a uniform and sufficiently strong pressure is exerted upon them against the plate. By this means good chips, as free as possible from mush, are produced, and the capacity of the machine is rendered much greater. A further advantage of this construction lies in the fact that it is very easy to remove foreign bodies as they invariably collect at the narrowest part of the channel and can be taken out through a trap-door there. This door can be used also for inserting and replacing the knife-holders.

The number of **knife-holders** which are fitted into the horizontal plate varies greatly. Aside from the fact that a plate of large diameter will require more and larger knife-holders than a smaller plate, the number of knife-holders in plates of the same diameter depends upon whether the construction of the plate permits bringing the knife-openings close together, or whether the knife-holders themselves are wide or narrow. Most knife-holders are placed in a plate which is strengthened on the under side, so that at the inner cutting circle the corners of the holders can almost touch one another without materially lessening the rigidity and strength of the plate.

For the plates most used in Germany, the knife-holders have a length of 11 inches clear and a breadth of from 3½ to 7 inches. Where larger plates are used, of course larger knife-holders are necessary. The construction of these knife-holders varies greatly, and every year improvements are recommended.

The chief requirements of a good knife-holder are:

1. It should be made of a good, hard material which wears away but little and is not easily broken.
2. It should be of solid construction without any parts which are easily worn out and difficult to replace.

3. It should permit the ready passage of the beet-slices.
4. It should have arrangements for unscrewing the knives and setting them at the right height, and be removable easily and quickly from the plate.
5. There should be an arrangement for placing the holder in the correct position, so that the knife has the right slope.
6. The holder should exactly fit into the openings in the plate so that there will be no exposed edges or corners at any place.

If the knife-holders fulfil the above requirements, it is a matter of indifference how they are made; the simpler they are, the better for practical work. Holders which fill some one of the above conditions particularly well and which are specially praised with regard to that one particular should be carefully examined to see whether they satisfy the other conditions as well, which is frequently not the case.

For fibrous beets, or to prevent small stones from getting into the machine with the beets, guards have been tried the front edges of which do not run parallel with the knives, but are hollowed out so that only thin points reach close up to the blades. These points are sufficient for holding the beets, but let the fibres, and particularly the small stones, fall through the openings before striking the knives.

The knife-holder must exactly fit into the plate, for every projection on the side or upon the surface of the plate against which the beets strike, throws them out of their correct position, the result being bad slices. Consequently new knife-holders will not, as a rule, fit old plates, for the latter are usually somewhat worn away by use. For the same old holders are not suitable for new plates.

The **knives** which are used for the smaller plates are always $5\frac{1}{2}$ inches long, so that two of them can be screwed into one holder. The width of the knife is determined by that of the holder, and its thickness is from $\frac{1}{4}$ to $\frac{1}{3}$ inch. The different kinds of knives now

in use may be divided into three classes: "Dachrippen," Königsfelder, and Double knives.

The **Dachrippen, or ridge knives** have the advantage of great efficiency because the beets are sliced with a single cut. They are made in very different forms; the number of the roof-shaped ridges varies from twenty to forty to the knife, so that they are from $\frac{1}{8}$ to $\frac{1}{4}$ inch apart, and the slices are of the same breadth. They are made by grinding steel plates.

The **Königsfelder knives** make only half a cut at a time. Their ridges are $\frac{1}{8}$ to $\frac{1}{4}$ inch apart. It is much easier to sharpen them and they are not so readily covered with fibres as the former. They are either cut from steel plates or rolled from sheet metal.

If either of the above-mentioned kinds of knives be *correctly placed* in the revolving plate, only grooved slices will be obtained if the beets are held still while being sliced. The correct position of the Dachrippen knives is when all the cutting edges are placed in exactly concentric circles, while with the Königsfelder knives the cutting edges of all the odd cutting-blades should be concentric with the grooves of the even ones. As a matter of fact this correct position is never attained, and consequently there will always be found mixed with the grooved slices others of all sorts of cross-sections.

Since it is important for the uniform extraction of the beets that the slices should be as uniform in cross-section as possible, the so-called **"double knives"** have come into quite extensive use, by means of which triangular slices are obtained. These knives are placed in a holder, or else in two successive holders, in such a way that a "Dachrippen" or Königsfelder knife is immediately followed by a straight knife. The first knife makes a triangular slice and the next knife cuts straight through and also makes a second triangular slice. By this arrangement slices of more uniform cross-section are obtained than with any other knives, but their shape is less suited for good and rapid diffusion working.

On the whole it is impossible to recommend unhesitatingly one form of knife over another. Equally good results can be obtained with all three types if the necessary care is taken in sharpening

and tempering and placing them correctly in the holder opposite to the counter-blade. The knives are usually sharpened by means of bevelling- and sharpening-machines, of which there are many of suitable construction, but the blades should always be finished by means of a fine file in order to obtain a perfectly even cutting surface.

One of the chief requirements for good slices is that the beets should be well washed and free from stones when they reach the beet-slicer. This requirement is frequently not met, and where complaint is made that the slices are bad it is usually best to make the washing better and more thorough rather than try different experiments with knives and knife-holders of all sorts. Good slices are essential for good work in diffusion, so that even when it is necessary to make costly improvements in the wash-house, the cost is usually repaid by the increased efficiency of the plant.

The condition of the beets and their inner structure naturally has an important influence on the quality of the slices. It is not possible even with the best machinery to obtain perfectly satisfactory chips from beets with a hard and fibrous tissue, particularly when they have been pulled after having gone to seed. The same is true of rotten beets or those with the meat too soft. It is also impossible to prepare good slices when too many weeds and leaves are mixed with the beets, as there has never been any machine invented which is certain to catch these before the slicing-machine is reached. The knives soon begin to dull and more or less pulp becomes mixed with the chips. This difficulty has recently become more pronounced because of the inability of the farmer to obtain enough efficient labor to clean the fields and harvest the crop.

The beets are discharged from the slicing-machines either into trucks or barrows, or, what is more common, they are carried to the diffusers by mechanical contrivances (belt, screw, bucket, or the favorite rope conveyors).

CHAPTER IV.

EXTRACTION OF THE JUICE.

The sugar-beet consists of **cellular tissue** traversed lengthwise by vascular tissue and surrounded at the surface by epidermal cells. The **cells** have very different shapes, varying from globular to an elongated form; they are surrounded on all sides by a membrane, the cell-wall, upon which the primordial, or protoplasmic, utricle rests; within the latter is found the cell-contents and cell-nucleus.

The **size of the cells** varies greatly; in the round forms, the diameter averages about 0.04 mm. and the volume 0.000,033 cubic millimeters. The walls of the separate cells grow together and increase in thickness as the beet grows. The substance thus formed is called the intercellular substance. On account of the different shapes of the cells, the growth of the cell-wall does not take place in all places, but a great many hollow spaces are formed between the cells, the so-called intercellular spaces, which are filled with air.

It is impossible for juice to pass out from a living cell, because the protoplasmic utricle is practically impenetrable by the cellular juice. Therefore, the object of all juice-extraction processes is first to destroy the utricle, or to so change it that it no longer hinders the passage of the juice.

The destruction of the cells by mechanical means (grinding) has long since been abandoned. It is now the general practice to take advantage of the **effect of heat upon the protoplasmic utricle.** If the cells are heated to temperatures above 55°–60° C. (130°–140° F.), the utricle is detached from the cell-wall so that only the latter surrounds the cell-contents on all sides. This wall consists of a very thin and penetrable membrane, being

especially thin at the guttated places. The juice can, therefore, easily pass out from a cell which is altered by heat or "killed," and be obtained by expressing or diffusion.

Therefore, all of the present-day methods for obtaining beet-juice first exposes the sliced beets to temperatures of at least 60°–70° C. (140°–158° F.), and in fact this is usually brought about by mixing them with hot juice previously extracted. For the killing of the cells, it is immaterial whether this heating takes place slowly or rapidly and whether the temperature is 70°, 90°, or 100° C. Hence, the manner and degree of the heating is determined by other considerations.

A. Diffusion.

In processes based upon juice extraction by diffusion, the sliced beets are first of all heated by means of hot juice, and slowly lixiviated with water in a systematic manner. It is not yet entirely clear as to what takes place in the cells themselves; it is not known whether the cell-wall is everywhere a closed membrane, whether it is, therefore, a question of osmotic processes in the separate cells, or merely a case of simple lixiviation. The fact is that the sugar, although it belongs to the class of difficultly-diffusible substances, passes readily and rapidly from the "killed" cells into the surrounding water, or into aqueous solutions.

In the beet chips, however, there are only relatively few cells at the surface to come into immediate contact with the extracting liquid. The majority of the cells are in the interior and the juice within them must pass through other cells and through the intercellular spaces; the latter are partly connected with one another and form narrow canals in the intercellular substance. Such *movements of juice* in the cell-ducts are brought about by *diffusion*, and follow the laws which govern diffusion processes between liquids, or solutions, that are in immediate contact with one another without any separating membrane. The rapidity of such a diffusion is dependent chiefly upon the

size of the surfaces in contact with one another, upon the degree of concentration and the differences in the amount of dissolved substance present in the layers of liquid, and finally upon the temperature.

Beside these diffusion processes, which included the processes of a more or less osmotic nature that take place at the cell-walls, there is, furthermore, *a washing away of the cell juice* from those cells which were injured during the slicing of the beets. Those cells that came into direct contact with the knives are left open; the number of such cells varies with the thickness of the slices and amounts to from two to five per cent. of all the cells. The cell layers lying directly beneath are sometimes more or less injured by the pressure, and more or less smashed, but most of them remain uninjured.

Finally, there are substances contained undissolved in the beets, that dissolve more or less quickly in hot water, during the work. In a properly conducted diffusion process the aim is to prevent and restrict all such action as much as possible.

For carrying out the diffusion a battery of connected lixiviating vessels or **diffusers** is used. The number of diffusers in such a battery varies from six to sixteen. The smaller number is found in the so-called "shortened" or "divided" batteries which are worked with a very hot and slow current of juice, whereas the larger number occurs in those which are worked at a lower temperature and with a more rapid juice circulation. As a rule, most batteries in use to-day contain from ten to fourteen diffusers arranged in a straight line, and when more than ten in number in two columns for convenience of supervision and labor. The circular diffusion batteries, with the slicing-machine in the centre, which were formerly preferred, are not now built in Germany, although it is most convenient to look after and feed the cells in such an arrangement. The disadvantages are that more space is required, and it is difficult, as well as expensive, to combine two such batteries with a common arrangement for transporting and slicing.

The **form and capacity of the diffuser** also vary much. The

capacity varies from 500 to 2600 gallons, although at present a capacity of from 1300 to 2100 gallons is preferred. The quite small diffusers which were formerly in use in Austria on account of the government tax levied there (some with only a capacity of 40 gallons) have been discarded as being absolutely unpractical. But, on the other hand, too large vessels are often undesirable, particularly when the amount of beets to be handled does not correspond to the size of the diffusers and when the slices are not very good or too fine.

The shape of the diffuser should be such as to insure, as far as possible, a good and equal extraction at all places in the diffuser, but without hindering the passage of the liquor. Both requirements, however, cannot be met equally well. With regard to the shape of the diffuser, first of all the **relation of its diameter to its height** must be considered. Naturally the extraction of the beet-juice is better the higher the vessel and the less its diameter. But as the height of the space which is filled with beet-chips and through which the juice has to flow increases, the greater the resistance which the flow has to overcome. Further, when the diameter is small the size of the strainer in the bottom is restricted, so that the holes become partly covered with beet-chips and the passage of the juice is much impeded.

Experiments have been made to ascertain what should be the relation between the height and diameter of the diffuser. Specifications of general application cannot, however, be given, for the resistance to the passage of the diffusion-juice depends not only upon the length of travel in a single diffuser, but also upon the number of cells in a battery, upon the size of the free passage beneath the sieve bottom, upon the thickness and character of the beet-chips, and upon the way these act during the diffusion, particularly on being heated. The last two conditions are different in every factory and do not remain constant in the same house, so that it is clear that for every change in the method of working quite different relations must be maintained.

At the same time there are certain principles which should govern the choice of most diffusers. With very thin beet-chips,

it is preferable to choose low vessels of large diameter. With thicker slices, the height of the diffuser should be greater and its diameter less. For the ordinary methods of working and average-sized diffusers, cylindrical vessels, with a relation of diameter to height of $1:1\frac{1}{4}$ to $1:1\frac{1}{2}$, are usually preferred. The ratio 1:2 is only seldom met with, for on the whole it is preferable to increase the number of cells in a battery rather than to exceed the relation $1:1\frac{1}{2}$.

What has just been said applies to the vessels which are cylindrical from top to bottom. This form, for various reasons, has not always been chosen. Experiments, which will be mentioned again later on, have shown that the extraction at different places in the diffuser is likely to be very different. It was thought that this could be remedied by changing the form of the vessel, and in fact conical-shaped vessels have been devised and tried. It is not probable, however, that the form of the diffuser, unless it is very abnormal, exerts much influence upon the juice extraction; consequently such deviations from the cylindrical forms have been abandoned.

The **shape of the upper and lower part of the diffuser** is conditioned by the manner of filling and discharging. The upper part must be made so that the slices can be introduced easily and uniformly. The opening for filling and the neck of the diffuser should, therefore, be as large as possible, and the conical parts connected with it should not be too flat.

If the cell is emptied through manholes on the side, the lower part is usually cylindrical; the lower strainer is then flat and is of same diameter as the cell itself. Some cells, however, are made with the lower part opposite the manhole side rounded so as to facilitate the removal of the exhausted pulp. Recently diffusers have been built with a mechanical emptying contrivance, the lower part of which is shaped like a trough. In the trough is placed a screw which pushes the spent chips out through the manhole at the further end. The screw is set in motion, as soon as the manhole is opened, by toothed wheels that are placed outside the diffuser at the further end. In all cases when there is side

discharge, it is advisable to provide a valve for introducing water into the lower part of the diffuser on the side opposite to the manhole. Such a valve is opened simultaneously with the discharge-gate. This washing-out process, however, works only when there is an abundant supply of water, so that it is advisable to save the waste water for this purpose, collecting it in tanks.

In the case of diffusers with bottom-discharge, the lower part is cylindrical if the gate is of the same diameter as the cell; otherwise it is conical, tapering to the size of the gate. The sieves of this bottom-discharge type rest on the gate, or in the coned-bottomed ones follow the shape of the cone. In the latter form, it is very effectual to make the holes in the upper part of the conical sieve smaller or spaced more than in the lower part. When the gate is of large diameter, difficulties are often encountered if ordinary rubber rings are used to make a tight joint. It is better, therefore, to use rubber hose, so that when the cover sticks, steam or water pressure can be introduced through the hose and the cover raised.

It is very convenient to have the lower gates arranged to open and close from above.

Whatever their form, after the cells have been connected together to form a *diffusion battery*, the chief requirement is to have the diffusion-juice pass through as completely and unhindered as possible.

The following means are employed to improve circulation:

1. Increasing water-pressure on last diffuser.
2. Lessening back pressure from the measuring-tank.
3. Increasing diameter of pipes and valves.
4. Removing completely all air accumulated in apparatus.
5. Increasing the free openings of bottom sieves.

In most cases the most effectual change is made by **enlarging the free openings of the strainer in the bottom.** It is not sufficient to have the area a few times larger than the discharge-pipe, because the chips lying directly on the sieve cover or clog up most of the holes, especially if these chips are fine or soft. Hence the area of

the sieve should be the greatest possible, and those strainers are best which have the largest number of holes or slits of appropriate size and yet possess the necessary strength to support the weight of the chips.

Formerly strainers were often placed in the upper neck of the cell, but have been discarded as not only useless but harmful, since, being of small size, they impede the flow of juice just as soon as chip fragments from the preceding cells have stopped up the holes.

Increasing the water-pressure on the last cell is usually of doubtful expediency when the ordinary head between water-tank and measuring-tank is increased over 30 feet. According to the familiar law, the velocity of the flow increases only in proportion to the square root of the pressure. Moreover, every time the water-pressure is increased, the pressure on the strainer is increased also. If the chips are firm and hard, this does no particular harm, but if the chips are soft and fine, this increased water-pressure is likely to make trouble. Therefore this remedy fails when it is most needed.

It is also wrong to allow a pump to act directly on the diffusion circulation, for besides the excessive pressure, pulsation of the pump acts injuriously. Centrifugal pumps are less objectionable, as the pressure is more even.

Likewise, **reducing the back pressure of the measuring-tank** by putting a pump in the pipe-line between the battery and the tank is efficacious only in special cases. Further, this can make trouble by sucking air into the cells, if the suction is too strong. For the same reason, but more on account of complication and expense, it is impracticable to put centrifugal pumps on the overflows from every cell.

Attempts have been made to relieve the pressure of the chips on the strainers by hanging wooden beams or gratings from chains inside the cell, so as to take some of the weight. This has met with some success, but the difficulty of discharging spent chips is so increased that these contrivances are only made use of in emergencies, as, for instance, in working up frozen or damaged beets.

The bad **effect of large amounts of air** upon the juice circulation is explained by the fact that the juice goes from top to bottom, while the air tends to rise. Consequently, when a large quantity of air or vapor is present, especially when it is distributed between the chips throughout the whole diffuser, the circulation of juice has to overcome great resistance. For the removal of accumulations of air and vapor, blow-off cocks may be provided in the upper part of each cell, preferably automatic ones. Under normal conditions, when only water-pressure is used, blow-off cocks are unnecessary. If the juice in the last cell is forced out by compressed air, however, it can happen that, through leaky valves, some of the air gets into the other cells. In this case, apparatus for automatically removing air and vapors is very useful, likewise when gases are evolved from the chips during diffusions.

Whether the circulation is satisfactory or not, it is advisable in all cases to have pressure-gauges at each overflow. By this means the pressures prevailing throughout the battery are always known, and it can be seen at a glance where the pressure is most diminished and hence where the flow is meeting with most resistance.

Pipes and valves of large cross-section are excellent, but in many cases their advantage has been exaggerated. If the velocity of the current in the pipes is not greater than 3 to 3½ feet per second, there is not much use in enlarging them, for poor pressure must then result from other cause.

For **warming the juice** as it passes from one cell to another, juice-heaters, or "calorizators," are used, or this is effected by direct steam injection. In general the juice-heater is to be preferred, for in this case the juice can be heated with exhaust-steam at low pressure, so that the process is not so expensive as in direct heating, for the latter uses live steam coming directly from the boilers. However, the objection which has been raised against this method of direct heating, that it makes the final juice thinner on account of the water condensed in it, has not been verified by experiment. Unquestionably all of the steam is condensed so that

the outflowing juice will be diluted, but as the juice meets with fresh chips in the last cell and is not warmed subsequently, this dilution is not perceptible in the final concentrate. Again, it should not be overlooked that even juice-heaters have a bad influence on the density of the juice. Juice becomes more concentrated in the process of diffusion in proportion to the space taken by the chips in the cell, and less so in proportion to the space filled with juice alone; hence spaces which simply contain juice are wasted as far as diffusion is concerned, and the space taken by juice-heaters must be so considered. Moreover, juice-heaters sometimes have the disadvantage of causing loss by leakage; hence this loss is prevented by direct steam-heating.

In order to economize the steam used in diffusion, **warm water** is often used for obtaining **pressure.** For this purpose the water coming from the condenser hot-wells or the condensation-water from the evaporators is used, or that from special heaters warmed by the vapors from the evaporators and hence at no expense.

This water is usually warmed not more than 40°–50° C. (100°–120° F.), but can be hotter, if the cells have bottom discharge or are emptied by use of compressed air.

If the spent chips are not to be dried but immediately used as fodder or put in silos, it is absolutely necessary that they be cooled before pressing, since chips pressed while hot spoil quickly.

In this case two water-pipes are supplied so that the chips can be mashed with warm water and pressed out with cold, and, in some cases, finally rinsed with more cold water.

The Method of Working a Diffusion Battery is different in almost every factory. The only common features in the different methods are the routine, the almost invariable heating of the juice as it passes from one cell to the next, and the manner of circulation. The juice runs from top to bottom in all cells except in the one which has just been charged with chips, and which is filled from the bottom to expel air. With regard to everything else the process varies within pretty wide limits, particularly as to temperature, time of treatment, and density of juice. Since the number and size of cells in the battery as well as the properties of beets and

chips are very different, it is quite impossible to define any standard method of operation. Therefore directions applying generally can never be given, but only such fundamental principles stated as will help in working out the most favorable conditions for each factory.

The first condition for good diffusion work is to have water as pure as possible, soft and quite free from soluble impurities. Hard spring water retards somewhat the extraction in the last diffuser, but is otherwise quite suitable, inasmuch as most of the lime salts are removed during the carbonatation. Where good water cannot be obtained, the strength and purity of the diffusion-juice always suffers, particularly when factories have to use purified waste water from the settling-tanks for the diffusion; such water always contains soluble mineral and organic matter. All these substances are not removed during the purification of the juice any more than are the alkali salts in river-water which has been contaminated with brine and yet has to be used in certain factories; they contaminate the products of the factory and lessen the yield in proportion to the amount of juice that is drawn off, or, in other words, the more water there is present in the juice.

If only a limited supply of pure water is at the disposal of a sugar-factory, the amount of juice should be kept as small as possible and the water piping for the diffusion-water must be connected by means of special valves both with the pure water-pipes and also with the pipes containing the water that is ordinarily used in the factory. The pure water is then used for the mashing of the chips, as this water alone gets into the juice, whereas the impure water is used for pressure purposes and can be removed from the diffusion on emptying the cells. Instead of using water, compressed air can be utilized. In the last case, the removal of the dry spent chips is attended with difficulty except when, in bottom discharge, the lower manhole has the same diameter as the diffuser.

A diffusion which is satisfactory effects good extraction from the slices, and yields juice which is of the greatest possible con-

centration. The diffusion process is not, as has already been explained, and what was first assumed when this method of sugar-extraction was introduced, a simple diffusion action, but at the same time there is a lixiviation as well.

Even with very smooth chips many of the plant-cells are broken, and the proportion of these broken cells increases with the fineness of the chips. With ordinary, more or less rough, chips the number of broken cells is still greater, and from such cells the contents are simply washed away. Furthermore, the cell-walls and the intercellular substance, as well as certain solid substances contained in the cells, are partly dissolved by long-continued action of the water. This is particularly true of pectic substances and organic calcium and potassium salts.

While the beet-slices are under treatment in the diffusion battery, three different processes are taking place simultaneously namely:

1. The forcing of juice out of broken cells.
2. The dialysis of the soluble constituents contained in the killed but uninjured cells.
3. The gradual solution of the difficultly soluble constituents of the beet.

Whereas the two first processes, particularly that of dialysis, are designed to take place during the treatment, the third is an injurious side action and should be as much restricted as possible. Unfortunately conditions most favorable for diffusion also aid in the removal of the relatively insoluble substances.

The dialysis of sugar from the cells takes place more rapidly, the hotter and thinner the juice and the finer the slices. It is more complete in proportion to the length of process. Working slowly at high temperature, thin juice and fine chips are also the most favorable conditions for effecting solution of the comparatively insoluble cell-substance.

It is ever the business of the sugar-manufacturer to consider carefully what conditions are most favorable for greatest sugar-yield. At the same time he must remember that certain procedure

and conditions are mutually dependent. Thus, for example, the time of diffusion can be shortened by working at high temperature or by stronger circulation, but, on the other hand, working at a lower temperature is permissible if the time of treatment is lengthened or the slices are cut finer.

If it were possible to carry out the diffusion process with smooth chips of about the size and shape of linen thread, an almost ideal extraction would be effected, for the whole action would be complete in a short time. In that case only small vessels would be required, and there would be much less dissolved from the cell-walls and their relatively insoluble contents, and, moreover, the juice would be highly concentrated.

Unfortunately it is not possible to prepare such chips, and if such fine slices were exposed to treatment in the diffusers, they would not permit the passage of a sufficient current. Most factories cannot cut durable slices of a thinness of 2 mm., or any kind of smooth slices of uniform cross-section. The length of time required for the diffusion must be regulated by the time required to extract the sugar from the thickest chips. The greater the amount of the latter, the longer the time required for the process to obtain a good average yield of sugar, other conditions being equal. The thinner chips are almost completely exhausted, and from their cellular tissue considerable non-sugars are dissolved, while the thicker chips still contain considerably more than the average amount of unextracted sugar.

Hacked or mushy chips, when extracted to the same extent, give a juice which is not inferior to that obtained from firm and uniformly thick chips; at least, the contrary has never been proven. The inferior quality of juice which may be obtained from mushy chips must, therefore, be alone attributed to an uneven extraction. To how great an extent this takes place, and whether it is detectable in the diffuser juice or even in the purified juices, has never been settled. Since, however, bad, mushy chips can impede the flow of all the juice, or at certain points where masses of poorly extracted material occur, the aim should always be to prepare as good chips as possible.

With regard to the temperature of the juice in the battery, the upper limit is determined by the temperature when the chips begin to soften, or, as it is called, when they are scalded. Scalded chips lie so closely upon one another in the diffusers and upon the lower strainer that the stream of juice runs extremely slowly. This temperature at which the chips become soft varies with different beets. In general, it appears that freshly harvested, ripe beets can stand a higher temperature without injury than beets which have been stored; at all events, the fertilization and weather which the beets have experienced in their growth plays an important part. With sound beets the temperatures in the hottest calorizators can reach 75° to 80° C. (167° to 176° F.) with safety, and without running any risk of overheating them. It is worth mentioning, however, that the temperature prevailing in the diffusers is always a few degrees lower than that shown by the thermometer in the overflow-pipes. No beet-chips can stand a temperature of 90° C. (194° F.) without becoming soft. Naturally a good deal depends upon the length of time that the chips are exposed to the action of the heat, so higher temperatures can be used when the contents of each diffuser are changed frequently than when the work goes slower.

In working up unsound beets (i.e., those which have been frozen or are somewhat decayed), the application of high temperature is altogether out of the question, for the chips from such beets, so far as actual chips can be made from them, are originally very soft, and become still softer at a relatively low temperature.

The temperature of treatment is also different in a long battery than in a short one, and with batteries made up of small cells than with large ones. The shorter the battery and the smaller the individual cells, the greater the number of them which can and must be maintained at the highest temperature; indeed even the pressure-water must be quite hot. The fundamental principle must be to bring the chips as quickly as possible to a high temperature; for the cell becomes "killed" only at temperatures above 60° C. (140° F.) and any bacterial action ceases at high temperatures. It is possible, when the work is carried out

properly, to reach a temperature of 70° to 75° C. (158° to 167° F.) in the second diffuser, the slices attaining this temperature in about ten minutes.

In order to obtain **juice of the highest concentration,** which must always be the aim, as well as to obtain a good extraction, the slices must be surrounded during the whole process with the least possible amount of liquid. The concentration of the diffusion-juice at the same rate of discharge, and with otherwise similar conditions, will be greater in proportion to the weight of chips contained in the diffuser, or the so-called "feeding-capacity." Ordinarily this is referred to every hectoliter (26.4 U. S. gallons, or 22 imperial gallons) of capacity. In this respect the larger vessels always have a certain advantage over the smaller ones. By "ramming," 55 to 60 kilograms (120 to 132 pounds) of chips can be placed in each hectoliter of space, while in the smaller diffusers, particularly where the work is carried on rapidly and there is no time for "ramming," frequently only 50 kilos are placed in this space. Evidently the nature of the chips will play an important part in the filling of the diffuser, for thin chips and those which are from fresh beets will lie closer together than thicker ones and those from dried-up and withered beets.

From what has been said, the following **typical methods of working** can be distinguished which, according to the local conditions, have their advantages and disadvantages:

1. Plants with the longer batteries of 12 to 14 cells, of which 10 or 12 are under pressure, with a small capacity of 20 to 30 hectoliters (500 to 800 gals.). The chips must be very fine, the temperature maintained in the entire battery up to the last cell must be as high as possible, using warm pressure-water, and the duration of the diffusion working must be short, about 1 to 1¼ hours; the change of cells should be very frequent, and the circulation rapid. The amount of the diffusion-juice delivered will be somewhat larger than usual.

2. Plants with long batteries of 12 to 14 cells, each with a capacity of from 50 to 100 hectoliters (1300 to 2600 gals.). The chips must not be too fine, but as uniform as possible; the temperature must be high in the first cells, but fall more in the last than in the former case; the pressure-water should be cold or only lukewarm, the time of working should be from $1\frac{1}{2}$ to $1\frac{3}{4}$ hours, the diffusers changed less frequently and the rate at which the diffuser-juice moves should be slower than in the previous case. The amount juice drawn off can be diminished to about 100% of the feeding.
3. Work with a short battery of 6 to 8 large cells. The chips should be as in Method 2, the temperature throughout the whole battery as high as possible, the pressure-water warm, the duration of the diffusion shorter than under Method 2 (about $1\frac{1}{4}$ to $1\frac{1}{2}$ hours), and the diffusers should be changed even less frequently, the rate at which the juice moves should be slower, but the amount of the juice should be a little greater.

If the size of the batteries in a given factory is taken into consideration, it will not be difficult to determine from the above three typical methods of working how to run the factory to the best advantage, in order to obtain juice as concentrated as possible and a good extraction of sugar from the beets.

How far the extraction of beet-chips should be carried depends on circumstances. If the battery is comparatively small and the quantity of beets large, it would not be right to attempt to get high juice-extraction at the expense of time and labor for treating the increased volume of juice; for the gain in sugar would be fully covered, if not more than balanced, by the smaller daily output, by the sugar-loss of the beets in storage, and the increase in coal consumption made necessary. If, on the other hand, the battery is especially large, it would not be good practice, when working under constant conditions of juice-extraction, to fail to increase

the sugar-yield by using the most appropriate temperatures and treatment, through fear of the juice from the last cell becoming impure enough to injure the yield.

While this latter notion is widely prevalent, it is only worth consideration in special cases, as when working up decayed or frozen beets.

With sound, ripe beets it is true that the undefecated juice from the last cell often has a very low purity, for the water dissolves, according to the nature of the beets, more or less non-sugars, particularly the parapectinates, in the form of lime and potash salts, but the calcium pectinates are precipitated by defecation and carbonatation, and the potassium salts are converted into potassium carbonate. The sirup from this purified juice after proper neutralization is readily grained so that sugar can be profitably made from it with no increase in cost of labor or coal. The alkali carbonates and the alkali sucrates which are always present to some extent in the defecated and carbonatated after-juices obviously must be cautiously neutralized if these juices are worked up by themselves. When worked up with the rest of the diffusion-juice, as customary in factories which extract the beets very thoroughly, they do not act injuriously but favorably, because the thin juice usually contains calcium salts which unite with the alkaline carbonates to form a precipitate of calcium carbonate. If such soluble calcium salts are not present in the juice after it has been defecated, then the carbonates of the alkalies, and especially the sucrates, must be changed to alkali sulphites by thorough saturation with sulphurous acid.

With regard to the limit to which the juice-extraction may be carried, it should be noted that the chips, as has already been mentioned, are extracted to different extents in different parts of the diffuser, and that thicker chips are extracted less, both as to the sugar and the non-sugar, than thinner and pulpy ones. As to the **extraction in different parts of the diffuser,** the results obtained from experiments have not been altogether concordant. On the whole, it can be said, as might be expected, that the amount of sugar retained by the pulp is greater, the lower the chips are in

the diffuser, so that the chips in the vicinity of the strainer contain at least 0.1 to 0.2 per cent. more sugar than those at the top. If the strainer is conical, as the case with diffusers which discharge at the bottom, the extraction in the middle of this conical part is likely to be very deficient in case most of the juice runs through the upper holes of the strainer. In large diffusers with the cylindrical part surmounted by a flat top, a high sugar-content is sometimes shown by the chips which remain in the upper corners. All these differences in the extent of extraction are of not much significance if the chips are as a whole very thoroughly exhausted, but they are worthy of more consideration when the entire extraction has been so poor that the chips on an average retain 0.5 per cent. or more sugar. This fact also argues that the extraction should be made as complete as possible, because only then does the actual sugar-loss correspond to that found by research experiments.

In judging the extent of the extraction, it must not be forgotten that in the removal of the spent chips the use of considerable wash water may cause a further lowering of sugar content, so that the sugar in the discharged chips is less than that of the chips in the diffuser. In estimating the sugar losses, the large amount of this waste water must be taken into consideration. On the other hand, when the diffuser is discharged by compressed air, the sugar-content of the chips is invariably greater.

Sometimes, in spite of good chips and correct procedure, an unusually high sugar-content will be found in the extracted chips. In such cases, the method of analysis should be changed, either by using a larger amount of lead acetate, or making an alcoholic extraction. If the apparent high sugar-content is not explained in this way, then a double polarization of the alcoholic extract must be made.

The **juice-extraction,** or the amount obtained from 100 kilograms of the beets, is dependent on the method of working. Before increasing this amount, in case the extraction is insufficient, the attempt should first be made to improve the process by heating up the last diffuser to a higher temperature, or by improving

the filling of the cells, while keeping the same rate of juice-removal.

The measurement of the amount of juice drawn off is usually effected in an open juice-heater. The height of the juice in the tank is either determined by an ordinary float or by an automatic apparatus with a signal attachment. This measurement, however, must be regarded as very inaccurate, or at all events insufficient for obtaining accurate data. Sufficiently accurate figures can be obtained by measuring the juice in a tank with an overflow, and this tank, after each filling to the overflow-point, must be completely emptied. The capacity of the tank is determined by weighing the amount of water which it holds. If the overflow is so arranged that it can be easily raised or lowered, so that the amount of juice removed can be easily regulated, such a measuring-tank will fill all requirements, and the use of automatic measuring-appliances, of which there are many of satisfactory construction, is unnecessary.

Frequently the juice from each extraction is tested by the spindle, and if care is taken to have a good average sample, such a test is of great value. If, on the other hand, it is desired to regulate the amount of juice drawn off according to the density of this sample, taking more in case the density is high, and less if low, this idea does not seem to be a good one. It is superfluous in the first place, because the beets are already well mixed in the slicer, and the chips likewise are so well mixed that the individual feedings of a diffuser during the day cannot vary appreciably in sugar-content. Consequently the density of the juice will not differ much if the cells are fed alike. Furthermore, the density of the juice and the extraction of the chips depends upon so many conditions other than on the amount of juice drawn that any attempt at regulation often causes more harm than good, even if certain cells actually do contain amounts of sugar different from the average. It is best, therefore, to change the amount of juice drawn off, only when the sugar-content of the exhausted pulp is abnormal and cannot be improved by other expedients. Such a

regulation is only necessary after considerable intervals of time, and the ordinary measuring-tanks give all necessary facilities.

It has been found by experiment that concentrated diffusion-juice usually is purer than thinner juice, and this is particularly true when the pressure-water is impure. For this reason, and also in order to economize in the amount of coal used, the aim is to make the amount of juice drawn off for a given amount of beet-chips as small as possible. Many factories only draw off 100 liters (26.4 U. S. gallons) for 100 kilos (220 pounds) of beets. More than 105 to 110 liters should not be drawn if the cost of coal is high, and in case the extraction is then unsatisfactory it is best to improve the process in other ways.

There is one sure way of finding out whether **the adopted method of working the diffusion is the correct one,** although requiring so much time and labor that it is seldom used in practice. The method consists in taking samples of juice from each of the different cells of a battery at the same time and examining them for the sugar and purity. From the sugar-content, the gain made in each single diffuser is determined. If the values thus obtained are plotted upon coördinate paper by taking the number of the cell as the abscissa and the increase in per cent. of sugar in the juice as the ordinate, a curve is obtained which, if the method of working is correct, will have a regular form. If the work is being improperly conducted, the curve will be very irregular, showing that the extraction in the different diffusers does not take place regularly and equally, and consequently the efficiency of the battery is not what it should be.

It is not always possible to judge the value of juice from its purity, because not only is the nature of the non-saccharine material very different, but it is not known which and how much of these substances will be removed by the subsequent processes of defecation and carbonatation. It therefore sometimes happens that a diffusion-juice of low purity will yield better massecuite than a purer juice. At the same time, "apparent purity" tests of diffusion-juice have a certain practical value, as they frequently enable conclusions to be drawn as to subsequent working and the difficul-

ties likely to be met. Such conclusions, however, are only reliable when many purity determinations are made systematically; only by such tests is it possible to judge whether a change in the conduct of the diffusion would be advantageous, especially as to time and temperature.

It is quite wrong to judge the efficiency of the work by comparing the purity of diffused juice with that of expressed juice, and to conclude that the former is better in proportion to its greater purity. Further, it is a well-known fact that the purity of expressed juice varies with the fineness of the pulp and the amount of pressure applied, and that beets raised under different conditions will yield different amounts and qualities of juice when pressed. There is no characteristic pressed juice which can be taken as a standard, and consequently such comparisons are useless.

Conclusions as to the efficiency of a factory method can be drawn only by comparative experiments with the diffusers. Certainly it is still doubtful whether the laboratory test, which is a mere digestion process, has any practical worth as a criterion of the work on a large scale; yet a juice obtained by digestion or in similar manner, if made from the same pulp, is certainly to be preferred to expressed juice for comparing with diffusion-juice.

The best way to judge of the effectiveness of a diffusion process is to make comparative experiments with two batteries working the same beet material. Inasmuch as it is difficult and expensive to arrange for such experiments, as a rule the actual results of parallel researches made with small experimental batteries must be depended upon to regulate factory control. In general, the vital points to be kept in mind are to maintain good extraction and concentrated juice, using systemized method and regularity in running.

The changes which the constituents of the beets undergo in any special diffusion process are but little understood. The chief constituent, the sugar, speaking generally, suffers no perceptible change even if the diffusion is slow and at high temperature, for many experiments show no increase in the amount of invert-sugar,

or at least only a doubtful one, and doubtful in so far as it is uncertain whether slight increases in the amount of invert-sugar actually occur from the sugar in the battery or whether substances with a reducing action are not formed from other constituents. The amount of reducing substances in the diffuser-juice amounts in general to from 0.05 to 0.15 per cent., according to the amount present in the beets. Of the albuminoids, a greater amount appears to remain in the beet-pulp the hotter the diffusion. The amount of acid present in the juice varies but slightly. Its acid reaction is partly due to free acid and partly to acid potassium salts which were either originally present in the beets or were formed during the diffusion. The amount of pectic substances which go into solution, and of difficultly soluble potassium and calcium salts, increases with the duration of the time of working and with the number of cells in a battery. The method of cultivating the beets and their ripeness also has an important influence upon the solubility of all these substances. Beets which have been unnecessarily strongly fertilized with potash and nitrogen will always yield larger amounts of this non-saccharine material than beets which have been normally fertilized or with sufficient amounts of phosphoric acid; not only as this non-saccharine material is present in greater quantities and in a more soluble condition in the former, but because such beets are always more difficult to extract sugar from, so that it is necessary to make use of higher temperatures and expose them to a longer diffusion. The constituents of frozen or decayed beets undergo greater changes during the diffusion, particularly when they are worked up hot and slowly; the amounts of invert-sugar and acid as well as of pectic substance being notably increased.

Recently, particular attention has been paid to the **action of micro-organisms and ferments** upon the juices, especially during diffusion. Ferments have been found in the beets themselves—namely, invertin and a zymase. Micro-organisms, on the contrary, are not present in healthy beets; they and their germs get into the diffusion with the dirt and dirty water, as well as in the factory supply. Their number depends entirely upon the

conditions prevailing in individual factories. Dirty beets, and those washed with impure water, naturally introduce more of such forms of life into the diffusion than do beets which have been well washed and rinsed with pure water. Good spring water and river water containing but few germs. Polluted water, or the purified water which some factories are compelled to use, contain a great many of them. Consequently, the number of micro-organisms and germs in the juice of the first and last diffuser may rise to many thousand per cubic centimeter.

Among these micro-organisms, however, many are found which have no action upon sugar. Those that act upon the sugar are chiefly *Leuconostoc, Bacterium coli, Bacillus mesentericus,* and *subtilis,* and related species.

If the forms of life present decompose sugar, it is evident that corresponding decomposition products must appear, since almost every individual kind of micro-organism produces a characteristic product. As a rule, the sugar solution becomes acid, but sometimes it turns alkaline. Invert-sugar is formed in many cases; at other times it is either not formed at all, or is decomposed as fast as it is formed. Not a few bacteria produce slimy or gummy substances, others alcohol and various gases such as carbon dioxide, methane, hydrogen, etc. The presence of micro-organisms is often recognized by the appearance of such gases, even when the amount of sugar decomposed is small. In other cases it is more difficult to detect the action of bacteria, as the qualitative detection of the decomposition products is in many cases difficult and the quantitative estimation altogether impossible. There is no question, therefore, but that when the conditions are favorable to bacterial action, large amounts of sugar may be decomposed without superficial examination showing any indication of such decomposition.

The most essential **conditions favoring the activity of micro-organisms** are, however, favorable temperature and sufficient time. Such conditions are never met with in a modern, carefully-conducted sugar-factory. Only very few bacteria are active at temperatures as high as 60° to 70° C., and these lose their

activity, or die, if the temperature is raised to 75° to 80°. The ferments, to be sure, still act at this high temperature, but the amount of ferments present in the beets themselves is very small and ferments are formed from micro-organisms only when the latter are active.

In the diffusion process the temperature in the diffusers is never below 55° to 60° C., except in the first and last diffusers and rarely in the diffuser next to the last; all other diffusers have a temperature of at least 70° C., and most of them are between 75° and 80° C. The chips and juice, therefore, are at temperatures favorable to the development of bacteria only for about ten minutes at the start and for from ten to twenty minutes at the end of the diffusion process. In this short time it is not possible for bacteria to form ferments or decompose appreciable amounts of sugar, especially as it requires some time for bacteria to become accustomed to new environment. Although it is sometimes asserted that sugar is decomposed during the passage of the chips from the slicing-machine to the diffusers, this has been disproved by many experiments. Cosettes from healthy beets will keep for several hours at ordinary temperatures without suffering any sugar loss.

If the diffusion and subsequent treatment is carried out properly—at high temperatures and with rapid movement of the juice—it is impossible for appreciable amounts of sugar to be decomposed.

The undoubted possibility that, in exceptional cases when proper conditions are not maintained, the action of bacteria *may* become marked should tend to make the manufacturer exercise all the more care in maintaining proper care. The use of preservatives, such as carbolic acid, acid sulphites, formalin, etc., is quite unnecessary, aside from the fact that the action of these preservatives is doubtful and they are expensive. Formalin, besides preventing fermentation, is said to have a favorable action as a precipitant of protein and peptic substances, but in order to obtain such action, the amount required makes it too expensive to be profitable. When bisulphites are used, of which

as a rule one liter of a 30° Bé. solution is added to 100 kg. of beets, hydrogen sulphide is frequently formed.

For practical purposes, the question as to the injurious effect of micro-organisms upon diffusion can be regarded as wholly answered, inasmuch as many experiments have shown that there is no perceptible sugar loss under normal conditions. All the sugar originally present in the beet, within the limits of error arising from sampling and methods of analysis, can be accounted for by that found in the diffusion-juice and in the waste products.

Many changes in the ordinary methods of conducting diffusion have been tried, without proving of much importance or finding permanent application in the industry.

The attempts to carry out a **continuous diffusion** in one cell deserve particular attention. The idea is certainly as old as the diffusion process itself, although up to the present time those arrangements which have been tried in practice have yielded a thin juice, and the extraction of the sugar from the beets has been incomplete and uneven. Most plans for this diffusion method exist only on paper. If it were possible to overcome the above-mentioned evils, the continuous diffuser would without doubt replace those now in use. A diffusion which is to take place continuously must be so arranged that the juice in a constant and steady stream meets the beet-chips moving in the opposite direction. Consequently, all disturbances caused by the strainers at the bottom of the ordinary cells, and the sugar-loss caused by the amount wasted in the water while emptying cells, will be avoided.

Other experiments have been tried of running the current of juice from the bottom to the top of the cell, with the idea of floating the chips and thereby preventing the stoppage of the holes in the strainer at the bottom. But the chips which are floated upward by the stream tend to stop up the holes in the strainer, which must then be placed in the top of the diffuser and cause about as much trouble. Furthermore, circulation from top to bottom is better because the denser juice does

not become mixed so much with the thinner juice which follows it.

In order to coagulate the protein matter in the cells of the beet-chips at the start, so that it cannot pass through the cell-walls, the chips, as soon as put in the diffuser, have been subjected to the action of steam or hot juice. It has even been proposed to construct the beet-slicing machine so that the beets will be sliced under a layer of hot diffuser-juice, so that the slices do not come in contact at all with air but are flushed by the juice directly into the diffusers. At all events, the advantage is gained that the beets are more easily sliced under the hot juice. But it is doubtful whether such a process can prove successful. During the short time that the chips are exposed to the air under ordinary conditions, there is no decomposition, so that the coagulable proteins do no harm to the juice. As a matter of fact, however, no appreciably greater quantity of protein passes into the juice when the slices are heated in the usual manner than when they are suddenly heated to above 70° C.

There is just as little advantage to be gained by heating the chips to 100° C. (212° F.) with steam or juice in a freshly filled diffuser.

The process is not advisable, moreover, because of the danger of sometimes scalding the chips in places and so hindering circulation. This can be obviated by treating fresh chips with liquor at 75°–80° C. from the previous diffuser, by pumping the juice through the chips and heater several times. The advantage of this method of working lies more in the fact that the fresh chips are at once subject to diffusion with hot juice. The extraction of the sugar from the chips also takes place more rapidly, fewer cells are required in the battery, and the juice is drawn off more concentrated. The process is also simplified so far as only the freshly filled cell needs heating, the other calorizators being unnecessary, particularly when hot pressure-water is used. The handling of the battery will be more complicated, however, inasmuch as each diffuser will require a special system of

valves and conducting pipes to run the juice back and forth.

With regard to the fact that the air contained in the chips proves a hindrance for the quick extraction of the sugar, the proposal has been made to remove the air from the freshly filled diffuser by means of a pump before mashing the chips with juice. The advantage gained by this method of operating is so slight that it is not to be recommended on account of the increased expense of installation and operating.

In order to enrich the wash-water from the filter-presses, which cannot be utilized in the dry clarification process, experiments in sending it back always to that cell in the diffusion, which holds juice of approximately the same concentration, have been tried with success. This method does not increase the amount of juice drawn off to the extent the wash-water has been added, since the juice is notably more concentrated. In general, however, it is hardly worth while to send this water back to the diffuser, because the work then requires much more attention, more control, and a new system of piping is necessary, and finally the advantage to be gained is not very great; with a continuous diffuser, on the other hand, such waste-waters, like the diffusion waste-waters also, could be utilized very advantageously.

Diffusion troubles sometimes make a different procedure necessary. Such irregularities may be caused either by the kind of beets, the inattention of workmen, or by a factory shut-down.

One of the most difficult tasks is to handle frozen or decayed beets successfully, or such as cause evolution of gases in the diffusion, without making the process too long, or getting poor extraction and impure juice.

Beets which have been thoroughly frozen by a strong and extended frost are not thawed by the warm water in the carrier and washing-machines. It is lucky if they are thawed enough to be washed clean of adhering dirt. In the beet-slicers it is impossible to obtain good chips from such beets; the ordinary knives are useless as a rule, so that "finger-knives" must be employed, and preferably those of roof ridge shape. Short chips

are obtained mixed with a quantity of mush, which makes satisfactory diffusion work very difficult. Frequently the chips, owing to the ice which they contain, when mashed with warm juice freeze together in solid lumps and do not thaw during the whole diffusion, or at least only partly. When the cells are emptied, there will be mixed with the normally extracted chips those from these frozen lumps, which will be little, if any, extracted. In order to avoid this trouble as much as possible, it is advisable, as the frozen slices are going into the cell, to run juice, as hot as practicable, in at the bottom. For the rest, it is necessary to work the other diffusers at as low a temperature as possible, because the cell-walls of the beet have been partially destroyed by the frost, and the chips consequently are apt to become too soft. Decayed or badly preserved beets must be also worked up at low temperatures. Consequently, to avoid undesirable pressure in the diffusers, the working temperature is lowered in proportion to the number of decayed or frozen beets.

Under such circumstances, no matter how the work is done, it is self-evident that the chips will be very unevenly exhausted. Of two evils it is necessary to choose the lesser, and in this case the lesser evil is the high sugar-loss, compared with the use of high temperatures, which effect complete stoppage of the circulation and hence make it absolutely impossible to continue the process. The high sugar-loss is likewise a lesser evil than extracting a very impure juice, which will always come from working slowly at high temperatures with such beets.

The evolution of gases in diffusion causes less trouble than formerly, on account of the process being now conducted hotter and more rapidly. This phenomenon is caused by fermentation brought about by action of bacteria, and is made evident by a strong frothing in the last diffusers. The cause of this frothing is that certain gases, particularly hydrogen and carbonic acid, are set free by the fermentation. It is not yet perfectly clear what kind of micro-organisms cause the fermentation; apparently they are anaërobic, as their activity is noticeable only within

the diffuser and ceases at once when the diffuser is emptied and its contents exposed to the air. The bacteria probably come from the soil, for the evolution of gases frequently occurs in working with very dirty beets. The best means of protection, therefore, lies in carefully washing the beets, and using pure pressure-water. High temperatures do not seem to kill these bacteria, for they are exposed to 80°–85° C. in the first diffusers. Their "temperature-optimum" lies between 40° and 50° C.

If in a battery the gas-evolution has taken place to the extent that the rate of flow of the juice is considerably diminished, the best way to remedy this is to draw off the juice immediately. It is ineffective, or partially so, simply to remove the gas by blowing it off through the air-valves, because the gas collects only partly in the top of the diffuser, while the greater part of it remains as a froth between the chips at the places where it is formed. The whole contents of the last diffusers are, therefore, foamy, and the current of juice is greatly impeded. The slower the circulation and the longer the time taken up by the diffusion working, the more gas will be generated, so that as a result, eventually the flow of the juice will stop entirely. If, however, the juice is at once removed and the diffusers are well washed out, usually this unpleasant occurrence will not take place again if the work is started hot and quick, and, with a shorter battery, avoiding interruption of the circulation. The increased loss in sugar owing to the amount remaining in the pulp, from this method of working, will in many cases be compensated by saving of time consumed in the operation and by the extraction of purer juice, since extraction in a foamy diffuser, even with slow working, is usually unsatisfactory. Incidentally it should be noted that there is danger from explosions, which can be readily caused by opening the diffuser in the presence of a naked light, and particularly there should be special caution in opening the lower manholes, as usually there is a strong pressure within the diffuser.

A phenomenon very similar to the gas evolution which was described above is sometimes observed if the beets contain large

amounts of enclosed air which cannot immediately escape during the mashing of a freshly filled diffuser. These gases, however, contain carbonic acid and are not formed during the diffusion, but are already contained in the beets, and on account of their small amount cannot cause much disturbance in the process. It is sufficient to remove them from time to time by means of air-cocks or vacuum apparatus on the diffusers.

The diffusion can also be impeded greatly by bad slices made from beets that have *gone to seed.* Such beets, particularly when they have old seed-stalks, possess a very woody tissue which dulls the knives in the slicer or covers them with fibres. If the farmer cannot be made to throw out all such beets when harvesting, there is no other help except changing the knives frequently and using either Königsfelder or "finger" knives with notched guards. Ordinarily such beets are met with only at the beginning of the campaign, when the early beets are delivered at the factory. The causes of the appearance of seed-beets are usually a long-continued period of growth, heavy and unequal fertilization, interrupted growth by night frosts, etc., to which the early beets are more subject than those which are sowed later.

Unpleasant interruptions and troubles in diffusion are often caused by lengthy stoppages in other parts of the factory. If this be due to a limited supply of chips (from troubles in the wash-house or in the beet-slicers), it is well to remove a measuring-tankful of juice every half-hour, and in this way cut out the last cell of the battery, in order that the juice move more slowly without dissolving out too much of non-saccharine material. This is not applicable when the trouble is at some later stage of the process, and in this case deterioration of the juice is the inevitable consequence.

This deterioration causes most trouble when the delay in process comes from slow-running filter-presses, because one of the principal causes of slow filtration, particularly in working up beets which are unripe and have been strongly fertilized with nitrogen, is due to the presence of pectin or similar substances, separating as a slimy mass in defecation. The amount of these

substances increases with the slow working of the diffusion. In such cases it is best to lower the temperature in the diffusion as much as is consistent with a satisfactory exhaustion of the beets, and, if possible, the hottest cells should be at a temperature of from 68° to 70° (155° to 158° F.). This usually extracts juice which will run better through the presses, and the work goes more quickly.

If the disturbance in the factory is more than temporary, the battery should be at once "sweetened off," so that, when the difficulty has been removed, the work can start fresh. With sound and good beets, however, a stoppage of twelve hours in the battery ought not to do much harm, if the temperature is lowered. Many factories consequently do not "sweeten off" the battery over Sunday, but, after drawing off the thicker juice, allow it to stand, in order to begin the evening work with the thinner juice. This practice, however, is not to be recommended, for the juice always deteriorates considerably. There is also no advantage, since the only reason for allowing juice to stand in the diffuser is to economize coal, and this is unnecessary, because the exhaust-steam is not needed for evaporation, and unless used will be wasted.

Inattention and carelessness on the part of workmen in charge of a battery will often cause much trouble. If the prescribed temperatures are not maintained, if bad chips enter the diffuser, or an insufficient amount of juice is drawn off, the result will be poor pressures in the battery, or a poor extraction. If excessive temperature in the battery is detected soon enough, it is advantageous to let cold water into the overheated diffusers and to push on as quickly as possible, so that the hot liquid is allowed to act upon the chips but a short time. If the circulation has already become retarded on account of the high temperature, the frequently employed method of shortening the battery helps only when it is known that the cell causing the trouble is near the last in the series; otherwise the damage is merely augumented by increasing the sugar-loss in the extracted residues.

If poor pressure in the diffusion battery is caused by beet-chips, which have been softened by too high temperature packing against the strainer and stopping up its holes, the difficulty can be overcome by reversing the flow for a short time. To do this, close the water-valve on the last cell and open the uptake-valve of the cell which is next to the one which has just been emptied. At the same time the water-valve on the freshly mashed cell is opened and the water now forces the juice in all the cells up through the strainer, so that the holes of the latter are freed from the clogging beet-chips. If, after a short time, the flow is turned in the original direction, the chips are no longer packed against the holes, and the pressure in the diffusion battery will be very much improved.

Leaky valves are often the cause of irregular working in diffusion. If a water-valve does not close tightly, water continually enters the diffuser, together with the juice, causing a constant dilution and an unsatisfactory sugar-extraction. If a juice-valve is not tight, the juice will likewise become thinner when it leaves the battery. The batteryman, therefore, must make sure that all the valves are tightly closed after each cell has been emptied, and that neither water nor juice escapes from the upper pipe discharging into the diffuser.

With good valve-washers of rubber or vulcanized fibre, and with the disc properly attached to the stem, there is seldom any trouble from leakage.

Invariably a **constant chemical control** of the diffusion, night and day, is absolutely essential. The mere fact that workmen know that every mistake will be detected stimulates them to greater care in running the battery.

Particular attention must be paid to starting and sweetening off the battery. **In order to start a battery,** three cells are filled with hot water by allowing the water to flow from one vessel to another and warming it in the calorizators, or the hot water is taken from another part of the factory (condenser-water, exhaust-steam, etc.). The temperature of this water should in general not exceed 70° C. (158° F.), otherwise the fresh chips are likely

to be scalded at the start, and consequently cause poor pressure. Frequently the beet-slicers are made a little thicker than usual at the beginning of the work in order to avoid bad pressure at this time. One after another, four or five diffusers are filled with the hot water, of course taking precaution to bring the juice to the right temperature as it passes from one cell to another. Then the first juice is run off into the measuring-tank, and usually half a tankful is drawn from each of the first two cells. When in this way the usual number of diffusers have been filled with chips and put in operation, the battery is ready to run in the ordinary manner, the prescribed temperatures being maintained and the last cells systematically cut out and emptied one after the other. Naturally the extracted pulp from the first diffusers is always very thoroughly exhausted, and usually retains but traces of sugar. The juice which is at first extracted is quite thin, and only becomes of normal density after six or seven cells are drawn.

The stopping or " sweetening off " of a battery is carried out in such a way that one vessel after another is shut out of the series after two measuring-tankfuls of juice have at intervals been withdrawn from each. Finally, four cells are left connected with one another, and juice is drawn away until the last juice contains only 0.3 to 0.5 per cent. of sugar. With poor beets it is best to put this limit higher, and to stop when the juice contains from 0.5 to 0.75 per cent. of sugar. Then the chips, even in the last diffuser, are sufficiently extracted; and if the amount of sugar which they retain is somewhat greater than is the case in the normal working of the battery, still this small loss does not come into consideration in comparison with the lowering of the purity of the juice. The last juice taken from the diffuser has a varying composition, depending upon the character of the other juice. Its purity is greatly diminished, and even after defecation is still very impure; it contains in particular many organic non-saccharine substances, which in the process of defecation form calcium salts to some extent, and render the further working-up of the juice more difficult, especially the boiling of the last week's after-products.

The exhausted chips are discharged through a manhole which is either at the side or the bottom of the diffuser. In order that the emptying may take place rapidly and thoroughly, it is necessary to observe certain precautions. First of all, by opening the upper air-cock the pressure within the cell is diminished; after this the lid to the lower manhole can be cautiously unscrewed. When the sputtering has ceased, the lower manhole should then be quickly opened, and immediately afterwards the cover of the upper man-hole should be raised. The contents of the diffuser will then fall out in a steady stream into a hydraulic carrier, which must be wide and deep enough to take up the mass of exhausted pulp. Diffusers which are provided with discharge-doors at the bottom are emptied very completely in this way, so that it is only necessary afterwards to rinse them out with a little water. In the case of cells with discharging-doors at the side, more or less of the chips will remain lying in the corner opposite to the manhole, but the amount of exhausted pulp finally left in the cell is diminished by flushing out with water from above, or, still better, by letting in the water beneath the strainer. When the latter method is employed care must be taken to see that the strainer is firmly fastened in position so that it is not displaced in the operation.

The **hydraulic carrier** has now come into almost universal use for carrying away exhausted chips. It is the simplest of all methods for transporting them in a horizontal direction. All the rules which were laid down with regard to the beet-carrier will hold here also, particularly with regard to the necessity of avoiding any damming up at the elevator. As the carriers always have considerable width and breadth, it is not necessary to provide much of a fall; one of about 50 mm. (2 inches) suffices. For the rest, the dimensions of the carrier are governed solely by the capacity of the diffuser; it is made deeper and broader in proportion as the cell is large, so that there will be room enough when the chips are suddenly dropped into the carrier.

Although the chips are shot out of the cells with a large amount of water, which amounts to more than the weight of the chips themselves, it is advisable, in cases where there is not much fall, to

pump the water which is separated from the chips by a strainer at the lower end of the carrier, back to the upper end. By this means the mass of exhausted pulp is moved forward at a uniform rate, and the elevator will consequently work better.

Only in those factories where, from deficient water-supply, the last diffuser is under air-pressure, is use of the hydraulic carrier out of the question. In such cases it is necessary to resort to the use of belt or screw conveyors.

Another method of removing the chips from the diffuser, and which at the same time is connected with the raising of the chips, depends upon the **application of compressed air** which enters at the bottom of the closed cell. Thereby the whole mass of pulp is thoroughly stirred up and nothing remains adhering to the lower strainer. If meanwhile a slide-valve at the bottom of the cell is opened as soon as the pressure has reached a certain height, the whole contents of the diffuser will be emptied through this valve and forced through a pipe to the pulp-press.

For raising the chips which are emptied into the hydraulic carrier, **bucket elevators** are commonly used. There is often more or less difficulty encountered in this operation on account of the buckets not taking up enough of pulp at a time; this difficulty is always met with in those cases where the boot of the elevator is too large, and where the water is too deep and flows too fast. The evil can be immediately remedied by increasing the water-overflow and making the boot smaller, or, still better, by leading the hydraulic carrier directly to the elevator, so that the chips go directly into the buckets. It is obvious that the buckets will be heavily loaded immediately after a diffuser is emptied, while in the intervals between the emptyings the elevator will have but little work to do. If it is desired to retain the advantages which a large boot offers in giving a uniform supply of the chips, it is a good idea to place in front of the elevator a horizontal shaft provided with arms, which, as they revolve, stir up the chips from below and propel them toward the elevator buckets.

Besides the bucket elevators, a screw conveyor is frequently used for raising the chips to the press, and serves to subject the pulp

to a slight pressure. Such an arrangement works very well for raising the chips, but is not very efficient with regard to drying them. Pumps with perforated pressure-tubes act upon the same principle.

From the elevators the chips are next carried to a **distribution device** over the chip-presses. Inasmuch as these presses work properly only when they are kept full of chips, it is necessary to have a regular and systematic feed. The presses, no matter what the design, are placed in a line, and the chips are carried over them by a screw or rake conveyor. As this conveyor discharges into each press through funnels, every one will be kept full as long as the supply of chips is sufficient. Occasionally those presses which get the residues, and are consequently unevenly fed, will work poorly. If the location of the presses permits, it is desirable to place a carrier behind the last filter-press to take back any excess of chips to the elevators. It is then not necessary to pay much attention to feeding-presses, as the process regulates itself.

The choice of **chip-presses,** which are of very various construction, depends upon whether or not strong pressure is desired. For high pressures, it is best to use presses that have specially made mantles and pressure-blades. In all cases particular attention should be paid to having a strong and finely perforated plate strainer, as well as means for taking away the expressed water thoroughly and rapidly in such a way that it is impossible for it to come in contact again with the chips. The thinner the layer of chips at the place where the pressure is strongest, the greater the amount of water expressed.

With all presses it is necessary to allow for a certain loss, as small pieces of the pulp will be pressed inevitably through the sieve. In order to avoid loss of this pulp, the press-water is carried back to the hydraulic carrier, so that the small pieces of chips will collect in the main body and be returned with it to the presses. If, however, it is desired to remove all the particles of beet, it is necessary to run the sweet water and the chip-press water through a **pulp catcher** provided with very fine slits or holes. The residues thus obtained, which are continuously removed from the strainer

by brushes or scrapers, are either directly carried to the pressed residues or to special presses.

With regard to the **value of using high pressure** in extracting chips, opinions differ. It is a fact that the harder the pulp is pressed, the greater the amount of valuable matter that is squeezed out with the water and lost, this loss being greater if the chips are not completely extracted. When the pulp is fed directly to cattle in the fresh condition, or when the pulp is allowed to sour, too strong pressing is to be avoided; in this case it is correct to press the spent slices until they contain about 10 per cent. of dry substance.

If, on the other hand, the pressed pulp is to be dried, the saving in fuel must be compared with the loss in nutrient matter. When fuel is high it is rational to remove as much of the water as possible by pressure, for in such cases the loss in nutriment is more than compensated by the saving in coal.

Not only the construction of the presses and the amount of pressure applied, but also the quality of the slices and the method of diffusion exert influence upon the proportion of dry substance in the pressed pulp. Thin and quite exhausted slices can be pressed better than thick or hollow ones, and it is also easier to press the pulp if the slices are fed to the presses warm or hot rather than cold. On the contrary, chips which have been kept in hot diffusion for a long time are more difficult to press than those which have been worked more quickly or at a lower temperature. The reason for this is to be sought in the fact that the cell-tissue is much swollen after a short period of overheating. It is advisable to work with warm or hot pressure-water in the diffusion, and to remove and press out the spent chips while they are still warm, when they are to be dried. When, for any reason, the exhausted chips cannot be removed from the diffusers while they are hot, it has been recommended to heat them again just before they are carried to the presses, or while passing through the upper part of the presses, by means of hot-well water or by direct steam. This treatment, to be sure, makes it easier to press the chips, but should only be resorted to in special cases, as the increased

amount of water to be pressed out and its more favorable extraction temperature, increases the amount of nutriment taken away from the chips. For the same reason the addition of lime to the chips is not desirable, although it makes pressing easier, since it lessens the digestibility of the fodder. Further hot-pressing is useless when the residue is solved, because, disregarding the loss in nutriment through strong pressure, these hot residues begin to ferment after a few hours, and do not keep in silos nearly as well as chips which ferment much more slowly and in a normal manner, as they do when cold-pressed.

B. Diffusion, Combined with Pressing and Recovery from Sweet-Waters.

Inasmuch as considerable amounts of sugar are lost in the waste waters in the ordinary diffusion process, it is easy to understand that even at the time the process was introduced, attempts were made to prevent these losses by working the sweet-waters back into process. This resulted in many difficulties; it was found, moreover, that as a result more sugar was left in the exhausted chips, so that there was no gain in the yield of sugar from the same amount of juice. Consequently this method of working was soon abandoned.

New incentives to **recover the sugar in the sweet-waters** have recently arisen in the difficulty of disposing of such water and in the preparation of dry fodder. If the waste water from the diffusers is used as pressure-water, it is disposed of in the simplest and most natural way; and, furthermore, considerable economy in the fresh-water supply results. The use of the waste water in this way causes a direct gain only when the residues are dried; in the dried chips there is present not only the sugar which is otherwise lost in the waste waters but also the total amount of non-sugars consisting of easily digestible substances. Only by drying is it possible to preserve these substances; when the residues are not dried they sour and the above-mentioned substances are converted into acids and other matter which has little or no food value. Such sour residues have no greater

value or nourishment than the sour residues obtained by the ordinary diffusion method. On the other hand, the practice of returning the sweet-water makes noticeably heavier and better dry chips than are obtained by an ordinary diffusion with drying of the press residues.

Working back the sweet-water permits, furthermore, greater variety in the extraction methods employed. Inasmuch as in this case all sugar-losses, or in fact all losses of dry substance, are completely avoided, it is not necessary to carry out the extraction so far in the battery as in an ordinary diffusion, but a greater or or less amount of the juice can be and is obtained from the pulp presses which is worked back either after the diffusion is complete or during the process. The greater the final pressure applied, the greater the amount of sugar which may be left in the chips when withdrawn from the diffusers without causing sugar-loss in the extraction. The press work, therefore, becomes an essential part of the process and regulates the juice extraction, according as a greater quantity of marketable sugar or a more valuable fodder is desired, thus determining whether the diffusion or the pressing is to be carried further.

The simplest way of working back the sweet-water is when **the usual diffusion-battery is employed.** Hereby certain disadvantages are likely to result which must be guarded against by special contrivances. These are troubles caused by bad pressure, foaming, and fermentation phenomena of the sweet-water in the battery.

The **cause of bad pressure** are the fine particles of beet which come in part from the slicing and partly from the presses. The coarser particles can be removed by pulp catchers, but the fine particles pass through the holes or slits of the strainer. The amount of fine material is small at first, and therefore uninjurious. As the work progresses, since none of the sweet-water is discarded, the amount of fine material increases and deposits upon the chips of the last receiver, which act as a filter, in a more and more dense and impenetrable layer that serves to check the flow of the juice and eventually stops it entirely. It is easy to prevent

this by simply drawing off portions of the sweet-water from time to time and allowing it to settle.

The waste diffuser-water (sweet-water), containing all of the pulp particles gradually collected in its passage through the chips, is run at regular intervals into a special tank, or a portion of the water is continuously decanted as it flows in a slow current through the tank. The fine pulp, settling to considerable extent to the bottom, is pumped with the surrounding water to settling tanks and pressed, making the bulk of the top-water containing but little pulp ready for the diffusion without further treatment.

The turbid portion of the sweet-water is clarified by settling, the clear water flowing to the pressure pumps of the battery, and the pulp finally deposited as a thick paste is worked up either by pressing or drying.

The greater part of the sweet-water thus is outside the diffusers only for a few minutes, so that there is not so much danger of interfering reactions taking place as would be the case if all the sweet-water was settled at one time. Only about 10 per cent. of the total sweet-water needs to be clarified, and as it settles sufficiently in from 30 minutes to an hour, it can be protected from change during that time by keeping it at a suitably high temperature.

It is advisable, however, to keep the water that is immediately returned to the diffusion at temperatures of at least 50°–60° C. (122°–140° F.) working at this temperature in the last cell and reheating the water to this temperature in special heaters before working it back. Fermentations and the foaming that is likely to result by the use of cold sweet-water are thus avoided.

The question as to whether it is better to **mix** the sweet-water and the water from the presses or to **separate them according to their sugar content** is of subordinate importance. The amount of sugar obtained from the diffuser-juice is determined by the amount of juice and its density and the latter depends upon the same factors as in an ordinary diffusion, namely upon the length of the battery, suitable temperature, as well as the nature and thickness of the slices. Even if by working back the separated waters in the following order, water from presses, overflow

water, fresh water, a smaller amount of sugar is said to be retained by the exhausted chips, nevertheless equal results can be obtained by adding a cell to the battery. For theoretical reasons, which are based upon the flow of the juice in the last diffuser, it seems improbable that the chips actually contain less sugar when the water is separated than when the mixed water is added to the first cell.

The work with mixed waste waters is simpler and more favorable as regards the settling out of the pulp. Only one pulp arrester is required for all the water and only one settling tank. Otherwise there must be separate collecting tanks, pulp arresters and clearing tanks for each different kind of water and obviously there must be some arrangement whereby the water can be introduced into the battery in the right order and proper amount.

By using either method, it is possible to arrive, within the normal limits, at any desired sugar-content of the juice or of the pressed residues. It is perfectly clear that the water running off contains considerably more sugar than is the case in an ordinary diffusion, even when the amount of juice withdrawn and the amount of sugar recovered from the juice is normal. On an average the waste waters now contain five or six times as much sugar and the pressed chips contain that sugar which would otherwise be lost.

When the work is normal, the sweet-waters in this process contain approximately 0.6–0.8 per cent. sugar and the pressed chips, according to the pressure, form 1–1.5 per cent. sugar. This relatively high sugar-content of the sweet-water, which makes it class with the thin sirups, shows why there is no advantage gained by carrying a part of the water back; for just as much sugar is lost as when all the water, of much lower sugar-content, is discarded. Either *all* the sweet-water must be returned to the diffusion, or it is better to carry out the process in the usual manner, for a *partial recovery* only makes the process more complicated without materially increasing the yield.

By lessening the number of cells in a battery, and the amount of juice withdrawn, juice-extraction is controlled more and more by the chip-presses. In this way it is possible to

have as much as 2 or 3 per cent. of sugar on the weight of the beets retained by the pressing and hence in the dried chips and under constant working conditions obtain a product containing a uniform amount of sugar.

Besides the sugar, it is evident that a larger amount of non-sugars will be present in the pressed chips. When working with a normal juice drawing, somewhat less non-sugars are dissolved out of the beets than is usual in the diffusion process, for in the latter fresh water is used to sweeten off, whereas when the waters are worked back, a juice containing quite a little sugar is substituted which will naturally dissolve less non-sugars than pure water will. The diffuser-juice, therefore, is always somewhat, if only a little, purer when the waters are worked back; and the pressed chips contain not only the non-sugars which would otherwise be lost in sweetening off and pressing, but also a small extra amount which has remained undissolved.

The waste waters always show an acid reaction which arises from acids dissolved from the cell substance, particularly from fine pulp. The degree of acidity depends upon the nature of the beets, the time they are kept outside the battery, and the temperature. When the work is properly carried out, the acidity does not increase, but varies within narrow limits. It has no influence upon the diffuser work or the quality of the juice, although it is true that in some seasons the strainers of the filter-presses, and the pumps, may be acted upon more than ordinarily. If this is found to take place often, it is best to use brass or bronze to replace the worn parts.

To obviate difficulties formerly encountered when the waters were carried directly back, it has been proposed to defecate such waters with lime; to carbonatate until neutral, and then to filter. In this way it is evident that the small particles of pulp which are likely to impede the flow of the juice will be removed most efficiently and the water will keep better. It appears, however, very questionable whether the gain is worth the expense involved in building an entirely new and extensive defecation, saturation and filter-press equipment, as well as the operation cost.

Furthermore, it must not be forgotten that defecation causes the removal of considerable quantities of valuable nutriment which when lime is not used would pass into the spent chips and be retained in the fodder. Again, purer juice is not extracted by this method, as those substances which are removed by this special defecation ordinarily would be retained by the chips or removed when the juice is defecated.

Besides the waste waters from the diffusers, the sweet-waters from the filter-presses, or from the boneblack filters, where still used, can be worked back in the diffusers by substituting this for fresh water, which would otherwise be necessary. By a very slight increase in the juice drawings the sugar otherwise lost in sweetening off can be recovered in the juice and the cost of evaporation lessened.

Juice extraction by alternate diffusion and pressing, like working back sweet-waters in diffusion, has already been much recommended, but it is only quite recently that the so-called "**press diffusion**" has been used in actual practice.

The apparatus required is one that works continuously; it consists of a number of separate members, each of which has a diffuser and a press compartment, all being connected directly together without valves or piping. In the press compartment there is a pressure-screw which serves to express the chips and at the same time force them into the diffuser compartment; the latter forms the connecting-chamber to the next cell. In this connecting-chamber the chips which have just been subjected to pressure come into contact with the juice from the following pressure-screw; the juice penetrates through the chips and is thoroughly mixed in by a stirrer and carried to the next pressure-chamber. Thus the chips travel upwards through the apparatus, which is vertical, passing up through all the other cells of the battery until they leave the last pressure-screw well pressed and more or less desugarized. The water required for the process enters under pressure in the outer chamber of the last press, the chips coming from the screw making a seal. The juice flows through the apparatus in the opposite direction to which the

chips are moving, leaving the last member in a concentrated condition.

This "press diffusion" has, in many respects, great advantages compared with ordinary diffuser work. A continuous process is always advantageous. All valves and arrangements for emptying are unnecessary; there are no waste waters, as they are immediately forced onward, as fast as they are formed, by the fresh water; the desugaring of the chips must take place much more quickly, because the diffusion is aided by the pressing and the juice is drawn off in a very concentrated condition.

The complicated mechanism required for the above process must be reckoned as a disadvantage. The ordinary diffusion work has the great advantage that is it not dependent upon any means of mechanical transportation; it is only necessary to provide arrangements for feeding the cells with chips and for removing the spent material, and at every station where the juice is to be drawn off very simple arrangements suffice, being in sight and easily accessible. In the "press diffusion" the transporting arrangements, the pressure-screws, and the stirring-apparatus, are entirely enclosed; in order to get at them, it is necessary to put the whole apparatus out of action and partly empty it.

According to present experience with pressure-screws, they only work well and uniformly when regularly fed. It is doubtful whether it is possible in "press diffusion" to always satisfy this condition, particularly when the apparatus consists of eight cells, more or less, and the customary extraction is desired.

The amount of power required for "press diffusion" is considerable and increases with the number of units employed.

As regards the wear of the different parts of the apparatus, particularly the strainers and the pressure-screws, there are at present no data; it should be noticeable in the course of time. There are no results of factory experience available from which an adequate opinion could be based, but there is no reason for doubting that results can be obtained by this process, as regards purity of juice and quality of pressed chips, equal to those of diffusion, utilizing sweet-waters.

C. Extraction by Pressure.

While in earlier pressure methods the sole object was to get as high a sugar-content as possible in the juice, the modern processes work also for pure juice by simple expression in ordinary presses, but besides make a fodder rich in sugar and nutriment.

In its original form, the "Scalding Process," as it is commonly called, was carried out by mixing finely divided beets with four or five times their volume of extracted juice, heated to about 100° C. (212° F.), so that the beets were at once brought to a uniform temperature of about 80° C. (176° F.). By this means it was supposed that cells were burst, but that no diffusion which was considered injurious could take place since the scalding juice always had about the same density as that in the beets.

In practice this process was not satisfactory, because the concentrated juice (as high as 20° Brix) foams too much and too much sugar remains in the pulp residue. As now worked, the process is somewhat different. The beets are cut into slices about two millimeters thick and immediately fall into a stream of six or seven times their volume of hot juice, by which they are carried along in a scalding trough of special design.

In the latter a constant temperature of from 80° to 85° C. (176° to 185° F.) is maintained by passing the juice stream, which carries the slices, through a heater. Behind the scalding-tank, the particles of beet are removed by a perforated screw through which the juice passes while the slices are being subjected to slight pressure. While still hot the slices pass into the the slice-press in which they are pressed to 30–35 per cent. dry substance and 10 per cent. sugar. The expressed juice passes through a foam remover, in which the foam is removed by means of steam or water, and then to the scalded juice. Pulp and sand eliminators are also placed in the piping. By introducing fresh water, or sweet-water, into the filter-presses, the juice is kept at 14° to 15° Brix, or, in other words, to about the same density as diffuser-juice.

It is obvious from the above that the process carried out in this manner is no longer one of simple pressing, but is combined with a true diffusion. It is different from the processes already described only as regards the degree and method of effecting the diffusion. In those cases where the scalding process is carried out side by side with an ordinary diffusion, it is customary to carry the diffuser-juice wholly or partly through the scalding-trough, using it, therefore, for the further enrichment of the juice.

The **amount of crude juice** depends upon the dilution and the pressing; it varies from 80 to 95 parts for 100 parts by weight of beets and is from 10 to 20 parts less than in the usual diffusion process. The purity of the juice is a little better than that of a normal diffusion, inasmuch as a somewhat greater amount of non-sugars remains together with the sugar, in the pressed residues. The increase in purity amounts to from one to two per cent., according to the nature of the beets, the degree of heating, and the amount of pressure applied. After defecation, the difference in purity becomes much less, because defecation of the diffuser-juice causes the removal of more impurities than does defecation of the scalded juice.

The ready **compressibility** of the scalded slices, as has already been pointed out, is not due to the fact that the cell has been burst so much as to the fact that the cells have been killed. It is, consequently, a matter of indifference whether the heating of the sliced beet takes place suddenly, or gradually during ten minutes, as in the case of ordinary diffusion. The method of working, therefore, could be changed without any resulting injury to the compressibility, so that the slices would be gradually heated to a temperature of from 70°–80° C. (158°–176° F.). To the favorable effect of the sudden heating has been ascribed the immediate killing of all the bacteria; but inasmuch as these must also lose their activity when the heating takes ten minutes, no advantage is gained. Furthermore, it is a matter of fact that the compressibility of the scalded slices is not one bit better than that of diffuser-chips which have lain for more than

an hour in juice at from 60°–80° C. (140°–176° F.). In the diffuser-chips, however, there is only water, or a very thin sirup, whereas a much more concentrated sirup remains in the scalded slices. The dried substance, being 15–17 per cent. of the weight of the residues from the ordinary process when well pressed, is increased to 30–35 per cent. Reckoned on the original weight of the beets, there are 25–30 per cent. of "sugared slice" residues which give 10–11 per cent. when dried, these latter containing 90 per cent. of dried substance and 30–40 per cent. of sugar.

The work according to this process is very simple and requires less attention than diffusion; although the slice-presses must be carefully watched to see that the expression is uniformly good. Every cessation of work must be carefully avoided, because if the slices remain too long in hot juice at a temperature of 90°–100° C. (194°–212° F.), they become soft, swell up, and are hard to press.

The real advantages of the scalding process lie in obtaining somewhat purer massecuites, in the possibility of working up larger amount of beets in the same amount of time, and in the economy of coal consumption as compared with diffuser work combined with drying the chips. The amount of space required for the drying of the chips is also less on account of their relatively larger amount of total solids. Of course a greater yield of sugar in the juice and dry products cannot be obtained by the press over diffusion, or by the diffusion battery where the sweet-waters are worked back, although it is evident that the yield will be greater than in the case of ordinary diffusion where the sweet-waters are discarded.

As disadvantages of the process should be considered the large amount of power required for the presses, and the fact that it is in all cases necessary to leave a large amount of sugar in the expressed slices. It is, therefore, impossible in seasons when the price of sugar is high and the value of the fodder low, to so change the manner of working that more sugar is obtained in the juice. In this respect the scalding process is less adaptable than press-diffusion, or ordinary diffusion with return of the sweet-waters.

Inasmuch as the yield of dry chips in the scalding process is almost twice as much as in the case of diffusion, the profit in the scalding process depends chiefly upon the *market value of the "sugar-slices."* According to their chemical composition, they should be worth about 10 per cent. more than ordinary dried chips. At this rate it is impossible to earn more by the process than by diffusion with return of the sweet-waters and drying the chips. It is still a debatable question whether "sugared chips" as fodder are worth more as fodder, on account of favorable digestive effects, than their composition would indicate. The future of the process, therefore, depends upon the final decision on this last question and on that of the fodder value of sugar for different animals.

A **modification of the scalding process,** in such a way that more sugar is obtained in a marketable form, consists in mashing the press residues after the first pressing with hot sirups and then subjecting them to another pressing after draining them as completely as possible. The dilute, impure sugar solution then mixes very quickly with the much purer juice which remains in the residues; the latter take up the sirup and yield a somewhat purer juice, so that the final result of the treatment is a purer sirup and residues which contain considerably more of the impurities of the sirup. This method of treatment, however, causes the loss of some of the advantages which are characteristic of the scalding process, namely, low expense of evaporation and production of an unmixed, unadulterated, dry fodder containing only the unchanged constituents of the beet.

CHAPTER V.

DRYING THE SPENT CHIPS.

The question of drying the spent chips from ordinary diffusion is still not settled for all conditions. It is an entirely agricultural one. In many sugar-houses the farmers take away the moist-press residues, preferring fresh or ensilaged fodder to dry. In such cases the sugar manufacturer has to govern himself entirely by the wishes of the contracting farmers; but if he grows his own beets, he should let figures decide the matter by making exact estimate of cost of equipment and the advantages and disadvantages of the fodders in his special case. Chief to be considered in such reckoning is the saving in transportation and freight by drying chips and the loss in food material caused by ensilage. This is greater the higher the temperature at time of pressing and storing the chips, the less care taken in storing them properly, the more sugar they contain, and the longer they are kept in storage.

In the ordinary method and period of ensilage, the average loss in weight and nutriment can be estimated as one-third. Speaking generally, it will be found advantageous to dispose of the fodder fresh during the campaign, drying the larger part remaining.

Sugary residues, such as obtained by working back sweet-water from diffusion or from the scalding process, obviously must be dried. In these processes, a drying equipment is a necessary addition to the plant.

The **drying apparatus** either work by direct firing or by steam heat. In the former, the hot flue-gases act directly on the chips; in the latter, steam is used for the heating-surfaces. In both cases the drying is aided by a strong air-current from fans.

For **drying with flue gases,** either ovens or revolving-drums are used; the former have trough-shaped masonry floors in which are paddles which work the mass over and over as it is moved along.

The **ovens** are seldom built on a level, but usually are in stories, one above the other. The furnace, which is on top, is fed with cheap coal, coke, or lignite, the draught being forced, so that the hot gases are practically smokeless, their temperature being not over 800°–1000° C. (1500°–1800° F.).

The gases pass back of the bridge-wall and come in direct contact with the chips and pass over them in the same direction in which they are moving over all of the shelves, which are invariably three deep. At once there is a large temperature drop, because the evaporation from the wet chips and consequent heat absorption is very great. At the end of the first shelf the gases are only at 200°–250° C. (400°–500° F.) and at their exit 70–100° C. (160–212° F.) according to the demands placed upon the oven.

By the simultaneous action of the paddles of the carrier, which toss them up and down as well as shove them onward, and the strong air blast, the chips pass through the oven in about half an hour, the lighter parts more quickly and the smaller and wetter portions more slowly. With a water-content of 6–12 per cent. they drop in regular manner from the lower shelf into a screw-conveyor and pass out of the oven.

The control of the apparatus is simple enough with ordinary care. Of chief importance is regularity in feeding and expressing the chips. Aside from this the heating only requires to be regulated so that the gas temperature at the end of the first shelf is 200°–250° and at the exit about 80°–90°. If there is a quick rise of temperature at the end of the first compartment, it is a sign that the feeding of the chips is inadequate. This should be increased immediately, or if the supply fails, the fire doors must be opened and the draught shut off so that the hot gases escape directly into the air. It is also important that the capacity of the fan is suited to that of the oven, in order to insure

proper dryness in the finished chips. With a little experience, this can be readily determined by feeling of them with the hand.

The strong draught carries away fine particles of the chips, which can be quite recovered by using a dust catcher, but the amount is small, perhaps 2–3 per ceut of the dried product.

In the **drum drying-apparatus** the chips enter simultaneously with the hot gases, passing through one or more drums, and are kept in motion by the revolution of the drum. The difference between the different drum systems lies in different methods of feeding the chips and of introducing the hot gases. As each individual drum or system of drums must be specially heated and fed with chips, while an oven with a capacity of several drums requires only one fire and one place for feeding chips, it is easy to understand why there is more attention required in keeping the drums filled with chips and the temperature right than for the oven, and furthermore the uniformity of heating which results from the massiveness of the oven is lost. Lack of sufficient attention in the case of drum-drying is much more likely to result in the overheating the chips, or exposing them too long, or, on the other hand, the pulp is often not sufficiently dried. In the latter case it will not keep nearly as well. If these evils are avoided, it is possible to obtain very satisfactory results from drum-drying.

Drying by steam is accomplished in jacketed troughs which are built one over another and which are enclosed in iron compartments. Bundles of pipes provided with paddles revolve in the troughs to stir up the minced chips and move them along, tossing them against the hot pipes. The jackets are heated by exhaust, the pipes by live steam. The water-vapors expelled from the pulp are removed by suction, and by means of the latter considerable amounts of hot air are brought into contact with the pulp, thus hastening the evaporation. Dust catchers are used to pervent fine material going through the suction-fans. For steam drums to be efficient, it is necessary that the chips be minced in a hashing machine. The temperature prevailing in the ovens while in operation is under 100° C., and in the troughs

the heat can scarcely exceed this figure even when the apparatus is stopped. Consequently there is no danger of the pulp being injured in any way through carelessness, for the temperature even in the steam-pipes is not high enough to cause browning; the chips retain their natural color and porous structure, in contrast to those which are dried by direct heat, which are always darker-colored and harder.

Although there is no danger of burning in drying by steam, yet the process requires care. If the feeding is not regular, the product is now too dry, now too moist. In the first case, the steam consumption is excessive, the heat passing off in the air which is sucked through. In the latter case, the chips will spoil and must be redried.

Compared with fire-drying, steam-drying has the disadvantage that the process cannot be forced and the operating cost is higher. Since the steam has to be produced by a separate furnace and a part is wasted in heating the air sucked through the apparatus, the steam process evidently uses more coal. On the other hand, cheaper fuel can be used. The equipment for steam-drying costs more and therefore the capital invested is greater, but there has been too little experience to judge of cost of maintenance. The advantage of steam-drying lies in the fact that a superior product is obtained, so that in many places it would be preferred in spite of the greater initial cost.

A multiple use of heat is not possible either in steam- or fire-drying. Therefore the aim should be merely to utilize as much of the direct heat from the fuel as possible. In the case of direct drying it has already been found possible to utilize 80 per cent. of the total heat produced from the fuel, although this economy has resulted somewhat at the expense of the character of the dried beet-chips; their appearance improves in proportion to the amount of air introduced during the drying and to the lowness of the initial temperature; both of these conditions correspond to a waste of fuel.

The kind of fuel and the manner of firing affects the color of fire-dried chips. Firing with coke, which obviously is too

dear, and with lignite, gives the lightest-colored chips. Of anthracite coals, only uninflammable dustless nut-coal is suitable, and this ought to be sprinkled with water before being put in the furnace. To keep the fine ash out of the chips there should be a large space behind the bridge-wall to allow the ash to settle and be drawn off, most conveniently by a drain. Automatic stokers work very well.

In order to save fuel, it has been proposed to utilize the heat of the **spent boiler-flue gases** in a special drying-apparatus, or for preliminary driers to the drying-ovens. A simple calculation will show that the heat of the boiler gases is barely sufficient to dry 50 per cent. of the chips. How the quality of the chips would be affected by such gases, full of soot and fine ashes, has not yet been found out. It is, therefore, not possible to say whether this method would have practical advantages. Experience has shown that only moist beet-chips, continually moving, can be brought in direct contact with hot combustion-gases. Dried chips continue to grow more or less brown, and the danger of burning is great. Boiler-flue gases can be used to advantage in steam-drying apparatus, but the necessary construction would be too expensive.

What has been said concerning the drying of chips from the ordinary diffusion process applies also to the "sugared" chips of other processes.

The question has never been definitely settled in regard to the **changes in the composition of the spent beet-pulp which take place during drying.** The sugar apparently remains almost entirely unchanged, at least if the firing is so conducted that the dried slices keep light colored. The digestibility of the other constituents do not seem to have suffered noticeably either in fire- or steam-drying, except the albumins which are affected if the heat has risen above 120°–130° C. (250°–270° F.). Hence the digestibility of browned or slightly scorched chips is always perceptibly influenced. In normal work there will be no scorching, as the slices never attain the temperature of the surrounding gases, especially at their entrance, where they still

hold much water. The vaporization is so rapid that the chips never get beyond boiling temperature. Feeding experiments comparing fire- and steam-dried slices show that while the digestibility of the organic material as a whole is somewhat greater in the latter, the albumins in the former show a higher digestibility number. These results are not altered in the case of rather dark-colored "sugared" chips which make a darker, moister product as the dark color is found to be due to but minute traces of decomposed sugar.

When soaked in water the steam-dried slices swell up quicker and take up more water than the fire-dried product, but this is in part due to the mincing to which the former have been subjected.

The **ash-content** of the directly dried chips, calculated upon the basis of dry substance, is always higher than that of the steam-dried chips, because the former are always contaminated with a little chimney-ash.

The increase is at most but small, seldom 0.5–1% of the dried substance. The freer the dried slices are from dust the better the fan works, hence the less ash; all of which is dependent on the efficiency of the dust-catcher.

The **amount of dried product** obtained from 100 parts of beets depends upon the amount of pulp and upon the method of juice extraction. By the scalding process the yield, as already shown, according to the juice concentration, is 9–11 per cent. "sugared" chips, these containing 30–40 per cent. of sugar. The ordinary diffusion process gives 5 to 6 per cent., according to the amount of dry substance lost in the press-waters, and to the care exercised in catching the pulp particles. These latter chips usually contain 2–5 per cent. of sugar. Using diffusion with recovery of sweet-waters the yield of dry chips, according to the lixiviation, lies between the limits mentioned.

If a properly working dust-catcher, such as the "cyclone," is installed behind the fan, **loss in chip substance** is at an end. The fine pulp particles, contaminated with 20–25 per cent. of ash, will be entirely trapped. The amount of this chip dust is trifling,

about 2 to 3 per cent. of the dried product. This material makes a good fodder when mixed with molasses, as it contains at least 75–80 per cent. of pulp substance, but owing to a large mineral content it should be fed only to animals with good digestions.

The **keeping qualities of the dried residue** are excellent, provided the drying has been thorough and uniform and the water-content is not more than 12–14 per cent., and it is stored in a dry place. When stored in moist places and against damp walls mold is very likely to form. Dried chips which are carried to a low water-content take up water again from the air till the percentage becomes 12–14, with, of course, a corresponding increase in weight. Twelve to 14 per cent is in fact the normal water-content of not only air-dried beet-chips but that of most dried organic material. "Sugared" chips should be cooled before storing, cooling-drums being used for this purpose.

Frequently the pressed chips, while still moist, are treated with hot molasses before fire-drying them, from four to five parts of molasses being added to about 300 parts of pressed chips, or the proportion originally present in the beets. The molasses is sucked up very quickly by the pressed chips, and the drying takes place in the usual way, although a slight caramel formation cannot be avoided, because the molasses collects mostly on the outer layers. It is better to make "molasses chips" by mixing the molasses into the dried chips as they come from the oven, still warm. The molasses is quickly absorbed by both classes of chips, if, of course, they are warmed to 70°–90° C. (160°–195° F.). Molasses can be worked into the dried chips up to half their weight or more and a dry fodder results which is easily preserved and handled. It contains 20–25 per cent. of sugar and is worth a good deal more than the "sugared" chips.

CHAPTER VI.

THE PRELIMINARY PURIFICATION AND WARMING OF THE DIFFUSION-JUICE.

The raw diffusion-juice as it comes from the diffuser is a pale-yellow or grayish-colored, turbid liquid which very quickly turns dark on exposure to the air, so that after a few minutes it becomes almost black. This blackening is caused by the oxidizing action of certain enzymes (oxydases) on a constituent of the juice such as tyrosin. This juice contains practically all of those substances which were dissolved in the beet and which have been extracted from it by diffusion. 96–98 per cent. of the sugar in the beet is extracted ordinarily. The following approximate amounts of non-sugars go into solution: of the ash, 65 per cent.; alkalies, sulphuric and phosphoric acids, and chlorine, 70–80 per cent.; lime, alumina, and ferric oxide, 20 per cent.; protein nitrogen, 15–25 per cent.; other nitrogenous matter, 90 per cent. The non-sugars go into solution in proportion as they are present in the beets.

The non-sugars which are not removed by the defecation and carbonatation of the juice can be termed the **injurious non-sugars**, as they lessen the sugar yield. Of course, it should be noted that precipitable non-sugars are also injurious in so far as they cause factory troubles, such as poor filtration and scale in vacuum apparatus. The really injurious non-sugars as defined are alkalies and soluble non-protein nitrogenous matter. Ordinarily the density of the juice lies between 12 to 15 degrees, Brix, corresponding to from 10 to 13 per cent. of sugar. The nature of the organic non-saccharine constituents is for the most part unknown; all that is established is that for 100 parts of sugar there are from 2 to 2½ parts of albumin, 2½ to 3 parts of other

nitrogenous matter, $\frac{1}{2}$ to 1 part of reducing substances, 1 part pentosans, and 0.4 to 0.8 part of oxalic acid. The inorganic constituents are chiefly potash, with some soda, lime, magnesia, phosphoric acid, sulphuric acid, chlorine, and small amounts of other acids and bases. The crude juice always shows an acid reaction, this acidity corresponding to 1–2 c.c. of normal acid in 100 c.c. of juice.

The preliminary purification serves to remove all the pulp and fibres of beet which are mechanically carried through the strainers with the juice, and furthermore to precipitate a part of the dissolved matter previous to defecation.

The removal of the stray pulp and fibres previous to defecation is something that should never be omitted nor its importance underestimated. These substances act detrimentally, first of all, by depositing upon the heating-surfaces of the calorizators and reducing their efficiency. In case they get as far as the defecation they are decomposed by the lime, forming slimy substances which to some extent contaminate the juice, though they are partly precipitated during carbonatation in such slimy scums as to impede filtration through cloth very much.

For the mechanical filtration of diffuser-juice, **pulp-** or **chip-eliminators** are used, of which there are a great number of different construction. In all cases the filtration takes place through a fine metal sieve, or strainer, which is kept free from fibre during the operation by means of brushes or scrapers suitably arranged, so that the residue which does not pass through the strainer is readily removed. These pulp-eliminators act better in proportion as the holes of the strainer are small, the filtering surface is large, and the contrivance for removing pulp efficient.

The pulp-eliminators must be arranged in the juice-line, between the battery and the measuring-tank, ahead of the heaters, so that the residues can be returned conveniently to the diffusers, and the juice in these residues recovered. The eliminators should discharge into a diffuser which is being freshly filled and which is already half-full of fresh chips before the contents of the eliminators are added. This precaution is absolutely essential,

because in this way the fine chip residues and fibres are then in the midst of the good chips and will not appreciably hinder the passage of the juice, whereas if they were allowed to rest upon the strainer in the diffuser they would stop up the holes and cause bad pressure in the battery. Even when the pulp is properly mixed into the cell it sometimes causes trouble. For this reason, in some factories, the juice is simply allowed to drain from the recovered chips, which are then mixed with the pressed residues. The slight sugar-loss is held to be the lesser of two evils.

The fact that albumins are coagulated by warming the juice, particularly when it comes from the pressed pulp, has caused the introduction in some factories of the so-called **"albumin-filters,"** through which the juice is filtered and said to be freed from albumin after it has been heated to 80° C. (176° F.). The whole idea, however, is based upon error, for by warming the juice only a very little albumin separates out, and in such a condition that it cannot be removed by filtration. The total amount of albumin in the diffuser-juice amounts to about 0.2 to 0.3 per cent., and of this only about 10 per cent. (or 0.02 to 0.03 per cent. of the juice) can be coagulated. This amount of impurity need hardly be considered, or at all events, will not warrant the outlay for an expensive apparatus. It does no good to acidify the crude juice with sulphurous acid before heating, because it curdles the albumin no better than heating alone. Furthermore, there is no sense in attempting to remove this coagulated albumin before the defecation, because the albumin is not acted upon by the lime under the conditions and during the short time of the defecation process, and hence it goes through the filter-presses in an unchanged condition. If, in spite of this argument, any one believes that these albumin-removers have proved useful, the cause is to be found in the fact that they have probably acted as good *pulp*-removers. If these albumin-filters are very capacious, so that in some places the juice is not in contsant motion, it is possible for them to be the cause of much harm; for in such cases they permit certain injurious changes through the action of micro-organisms.

The preliminary purification of the diffuser-juice has also been attempted by the use of sulphurous acid, aluminium sulphate, baryta, the electric current using soluble electrodes, and by electro-dialysis. These and similar agents do cause separations and precipitations of non-sugars as well as a partial decoloration. Inasmuch as nearly all of these non-sugars are likewise precipitated by lime, it seems purposeless to replace the inexpensive lime by other dearer agents which accomplish little if any more good; and even if they are slightly more efficient, the gain is not commensurate with the increased cost.

The Preliminary Warming of the Diffusion-juice.—In the measuring-tanks the juice from the diffusers has a very variable temperature; the latter depends upon the method of working and the temperature of the chips, so that with an ordinary method of working the temperature in the tank may vary from 0° to 40° C. (32° to 104° F.), but in most cases it lies between 25° and 35° C. (77° to 95° F.). In case the diffusion process is conducted so that the juice runs repeatedly through freshly-filled diffusers, its temperature at the tank may be as high as 70° to 80° C. (160°–180° F.), and in such cases it is ready for defecation without further treatment. It is necessary in most cases to bring the juice to the proper temperature by passing it through tubular pre-heaters, which may be arranged vertically or horizontally, and sometimes are open and sometimes closed.

The heating of the juice serves at the same time to coagulate those substances which are coagulated by heat, thus rendering them insoluble; in which condition they resist the decomposing action of the lime more strongly. The substances which thus separate out are to some extent albumins, but chiefly compounds free from nitrogen.

Generally **open pre-heaters** are used, because the tubes can be cleaned while they are in operation. They have the disadvantage of not being so efficient and of having the surface of the juice exposed to the air. They become more efficient if the passage of the juice is hastened by means of pumps, or screw

propellers, and if fitted with mechanical contrivances for cleaning the tubes while they are in use.

Closed pre-heaters are preferable to open ones, and in these the juice is made to run quickly through a series of tubes arranged in separate sections. In such heaters there is not so much precipitate adhering to the heating-surface of the tubes, and consequently their action is quite uniform.

The best heating arrangement consists of batteries of separate single heaters containing long tubes of small diameter and in which the juice is moved at the rate of at least one or two meters per second by means of pumps. Although there is but a slight deposition upon the heating-tubes when the juice is moved so quickly, yet it is necessary to provide each heater with suitable valves so that it can be shut out at any time and be cleaned wthout interfering with the process in any way. The efficiency of such heaters is so much greater that their heating-surface can be made considerably smaller than in the open heaters, or the steam by which they are heated may be at a lower pressure.

The capacity of these heaters should not be too great, because in such cases the juice will remain too long in the heater, and consequently the continued heating of the raw juice will injure it, causing, in particular, a perceptible inversion of the sugar. An acid reaction has no influence when the juice is heated the normal period, yet when acid juice is heated for some time at a temperature of 90° C. (194° F.) or higher, inversion begins. To prevent this, sometimes a little milk of lime (about 0.2%) is added, just before the juice reaches the heater, in order to make it slightly alkaline. This addition of lime is also said to lessen the deposition upon the heating-tubes. On the other hand, addition of lime to the cold juice is frequently found to have an injurious effect, causing the juice to run badly through the filter-presses. Hence preliminary defecation has not been practiced to any extent, and in most cases such treatment is wholly unnecessary.

Most factories have two of these heaters, or two systems of heaters, the first heated by vapor on its way to the condenser

from the last vessel to the multiple-effect evaporator, thus warming the diffusion-liquors to about 45° or 55° C. (113° to 131° F.) without expense, and the second heated by the vapors from the juice in the first evaporator, bringing the juice to the temperature necessary for defecation, that is, 70° C. (158° F.), or, better still, to 80° or 85° C. (176° to 185° F.).

Since at the start there are no evaporator-vapors for these heaters (and this is true of other heaters in the factory), it is necessary to heat them with direct steam or else with the engine-exhaust. At the beginning of the work, when the juice, apparatus, and heating-tubes are all cold, special attention should be paid to this heating of the juice, for if this is not done the whole process suffers.

Each heater must be arranged so that it can be cut out from the juice-line when it becomes clogged or leaky. In order to discover any leakage it is necessary to examine the condensed water regularly for sugar. In these preheaters there is more danger of loss by leakage than in the evaporators, for in the former the pressure is usually greater within the tubes than without, whereas it is exactly the opposite in the evaporators.

In order to prevent corrosion of the heating-tubes by ammonia vapors, here as in the evaporating-apparatus, suitable vents must be provided.

CHAPTER VII.

DEFECATION.

The hot, raw juice is next subjected to the action of lime, whereby it is purified, or *defecated.* Formerly it was the almost universal practice, still retained in some factories, to add milk of lime to the juice and then immediately saturate the saccharine solution with carbonic acid. When this was done a large part of the lime was changed to carbonate before it had sufficient opportunity to purify the juice, so that as a necessary consequence a much larger quantity was required than when carbonatation takes place by itself and in separate tanks.

Distinction is made between milk-of-lime, or *wet,* defecation and *dry* defecation. In both cases a part of the lime is dissolved by the juice, while the greater part of it remains suspended and undissolved. The solubility of lime in sugar-solutions depends upon the amount of sugar, the manner of adding the lime, and the temperature. At ordinary temperatures, if the lime is in contact with the thin juice for a length of time, approximately enough lime dissolves so that the proportion of calcium to sugar corresponds to the formation of a monosucrate of calcium in the solution. The higher the temperature, however, the less lime dissolves, so that at the temperature of 80° C. (176° F.), which usually prevails during the defecation, only 0.25 to 0.35 part of lime will be dissolved in 100 parts of the juice containing 10 to 12 per cent. of sugar.

The Wet, or Milk-of-lime, Defecation is carried out by the addition of a thick milk of lime of about 20° Bé. to the hot raw juice. The defecators are provided with a simple stirring arrangement for mixing quickly. When milk of lime is added directly to

the carbonatation-tanks the introduction of the saturation-gas mixes the liquid.

In smaller factories milk of lime is frequently prepared by slaking the lime in flat slaking-pans. It is much better, however, to make use of slaking-drums, similar to bone-black washers, for in these the slaking is more complete and without fatiguing labor. The last sweet water from the filter-presses is used for slaking water. Where this is not available in sufficient quantity, it is advisable not to use cold spring-water, but rather pure condensed water from the evaporating-apparatus or thin juice.

In order to remove soluble matter present in the lime it has been proposed, and the practice introduced in some factories, to slake the lime with a large amount of water, allow the liquid to stand, and then run off the clear supernatant liquid containing the soluble impurities. Most varieties of burnt lime, however, contain scarcely any impurities which are soluble in water, and of such only the salts of the alkalies are worth considering, for those constituents of lime which are difficultly soluble or dissolve very slowly, such as, for example, silicate of lime and alumina, will never be satisfactorily removed, for the simple reason that they are much more soluble in sugar-solutions than in pure water. It is difficult to see the advantage to be gained by the above method of slaking: the work is made harder and the advantage of using a freshly slaked lime is lost. The longer the slaked lime stands the less energetic becomes its action upon the juice, probably because caustic lime combines slowly with large amounts of water. Lime which has lain slaked in the pits for a long time acts slowly and only incompletely upon sugar-juice.

Dry defecation is done at the present time only by adding pieces of burnt lime about the size of one's fist to the juice at a temperature of at least 65° or 70° C. (149° to 158° F.). Using powdered lime has been found expensive, while this extra pulverizing is entirely unnecessary. Frequently, and particularly when the lime-powder is not added regularly, the pipes are clogged, the powdered lime balling up into a sticky mass which distributes itself slowly, or not at all, through the juice. The defecation then

takes more lime, is incomplete in its action, and the subsequent carbonatation is likewise affected.

When burnt lime is thrown into hot juice it immediately begins to slake. Since there is always a strong evolution of heat involved in the slaking process (1 lb. of lime sets free 360 heat-units, B.T.U.), and because overheating of the juice at one place is disadvantageous, it is necessary to pay particular attention to the construction of the tanks used for the dry defecation; this is especially true in the case of lime which slakes quickly and energetically.

The old-fashioned method of dry defecation, by which a basket having perforated sides was hung in the juice, should be discountenanced. For a scientific dry defecation the following rules should be followed:

1. The lime must come in contact with the juice in a flat layer.

2. The juice, and often the lime also, must be constantly kept in motion.

3. Emptying out of stones and other débris must be easily and rapidly effected.

These conditions will be satisfied if the lime is spread out in the tanks upon either a revolving or a fixed strainer, while the juice is kept in motion by means of a stirrer with arms both above and below the strainer. The pans must be provided with manholes through which the stones, etc., can be removed, or the sieves themselves should be removable.

Dry as well as wet defecation can be made a *continuous* process by allowing juice to enter at the bottom of the defecation-tanks and to overflow in the upper part, thence passing on to the carbonatation, the necessary amount of lime being added each time that a measuring-tankful flows through the defecating-tanks. A special valve is provided for emptying pans, being used when necessary to remove stones and sludge, a more or less frequent occurrence according to the nature of the lime employed.

The method of defecation to be preferred depends upon conditions having nothing whatever to do with the action of the lime itself; for, with respect to the purification of the juice, no difference has been found in results obtained with either of the two methods

when properly carried out, and theoretically it is difficult to see why there should be.

Dry defecation is preferable when there is but little sweet water from the presses which is available for slaking the lime and when the lime-ovens are in the vicinity of the defecating-tanks, so that no special transportation arrangement is necessary for bringing lime to them. Wet defecation, on the other hand, is employed in factories which find it advantageous thoroughly to sweeten off the filter-cake and where, the kilns are so situated that it is easier to pump up the milk of lime than to transport it in the form of dry lumps. The latter consideration is not very important, however, because it is always possible to place defecating-tanks near the lime-burners by pumping or running the juice there.

Another point in favor of dry defecation is the fact that the action of the lime is quicker and more energetic than in wet liming, so that by the former the same extent of purification may be obtained by use of a smaller quantity of lime. Furthermore, the juice when subjected to dry defecation retains a large amount of dissolved lime and passes on somewhat more rapidly to the carbonatation-tank, and consequently there is a more economical utilization of the carbonic-acid gas. Finally, it is questionable whether it is wise to sweeten off the filter-scum very much, but when this is not done there is not enough sweet water available to slake the lime. Hence in wet defecation it is necessary to use water at the slaking-plant, since it is not usually considered wise to pump either crude juice or the purified thin juice back there; consequently, all other conditions being equal, factories employing wet defecation use up a little more coal than those employing dry defecation. In passing, it may be mentioned that slaking the lime warms the juice, while in slaking with sweet water there is a slight cooling from the evaporation. In general, therefore, unless particular conditions work to the contrary, it may be said that dry defecation is usually preferable.

It should be mentioned that certain experiments with dry defecation have apparently shown larger losses in sugar and inferior purity of the juice than when wet defecation was used. These

experiments are misleading, however, because, from improperly carrying out the dry-defecation process, some insoluble sucrate of lime was formed which was not decomposed by the carbonatation which followed. Similarly the disadvantage of producing gray sugar, often attributed to dry defecation, is not in reality true, for when the gray color appears it is from other causes.

Insoluble calcium sucrate is formed in dry as well as in wet defecation, because the insoluble calcium salts formed by defecation have the property of carrying down with them soluble calcium salts, and therefore calcium sucrate. Insoluble calcium sucrate is precipitated in small amounts from all defecated juice if the latter is heated much after defecation; in this case there is more precipitate formed after dry defecation, for the simple reason that there are more lime salts in solution than in the case of wet defecation. It is, therefore, necessary carefully to avoid heating defecated juice until after it has been fully saturated with carbonic-acid gas, while all overheating as a result of the liquid coming in contact with the hot heating-surfaces must be guarded against. Consequently the temperature of the raw juice should be high enough to make it unnecessary to heat the juice again until after the completion of the first saturation process.

The action of lime upon raw juice is both chemical and mechanical. Lime acts chemically as a precipitant and decomposes the non-sugars; the **mechanical purification** is due to the fact that suspended matter is carried down with these precipitates. In raw juice not only fibres and fine particles of beets which were not removed by the pulp-eliminators are in suspension, but also all bodies thrown out of solution in warming the juice. There is also in suspension a certain amount of micro-organisms and germs which if allowed to remain in the juice too long make their presence evident in an unpleasant manner by inverting sugar and causing souring.

The slimy precipitate formed by the lime settles out readily at the bottom, the supernatant juice being of a light-yellow color, bright, clear, and absolutely sterile. It is easy to make a separation such as the above with expressed beet-juice; it cannot be done with diffusion-juice, although the latter filters easily when treated with sufficient lime.

The **chemical action of lime** upon the non-sugars is accomplished first of all by the lime neutralizing the free acid and acid salts present, and forming insoluble salts with a part of the organic acids and inorganic acids, particularly oxalic and phosphoric acids, all substances being precipitated which are insoluble in a solution alkaline with lime. The alkalies which were combined with the precipitated acids in the raw juice, such as ammonia and organic bases, are set free and act, together with the excess of lime added, upon the non-sugars. The alkalies, being the strongest bases, at once unite with those acids which give no insoluble compounds with calcium, to the extent that these acids are present in the juice, while ammonia and the organic bases remain uncombined.

Of the organic impurities remaining dissolved, many suffer a more or less complete decomposition, particularly invert-sugar, the amides, amines, and albumins. Those acids yielding soluble salts with lime and which are, therefore, not precipitated, unite first of all with any free alkali present, and finally with the lime.

Lime, therefore, acts upon the juice in the defecation process as a purifying agent, the purity being increased by the precipitation of the non-sugars; furthermore, it changes the nature of certain of these non-sugars without appreciably removing them. Both actions are very favorable for further working up of the juice, and certainly the latter is no less valuable than the former. In general, it may be said that the **amount of the non-sugars precipitated** is less than is commonly supposed. By defecation and carbonatation, the purity of the juice is only improved from 4 to 6 per cent. Of the 12 to 15 parts of non-sugar present in each 100 parts of dry substance contained in the raw juice, only one-fourth, or at the most one-third, is precipitated, being 30 to 50 per cent. of the organic matter, 30 to 40 per cent. of the nitrogenous matter, and 10 to 20 per cent. of the ash. On the other hand, the value of this **decomposing action** of the lime is not sufficiently taken into consideration. By the decomposition which these substances undergo many properties are lost which if retained would act unfavorably upon subsequent processes, and especially upon the crystallization of the sugar.

The alkalies present in the raw juice are not removed by defecation. A small part is indeed precipitated with the lime in the carbonatation, but by far the greater part remains in solution combined with acids (as carbonate and sulphite after carbonatation) or as free alkali, and is found again finally in the massecuite.

The amount of *free* alkali present in the defecated juice depends entirely upon the acids with which the alkalies were combined in the raw juice. If the latter contains many acids, like oxalic acid, parapectic acid, etc., that form insoluble compounds with lime and the amount of acid present after defecation is insufficient to unite with all of the alkali, a considerable amount of the latter remains free, which during the defecation and in the subsequent operations decomposes the non-sugars. In such juices, which therefore contain carbonates of the alkalies after carbonatation, a decrease in alkalinity during evaporation acts in no way detrimentally. Lime salts are not present, or at least only in traces. If the diffusion is good with a thorough lixiviation the amount of alkalies and their salts increase, as soluble alkaline pectinates are dissolved, while the lime salts generally decrease somewhat.

If, on the other hand, the acids originally combined with the alkalies form only soluble salts with lime, they unite with the alkalies set free in the defecation process, replacing the lime in these salts either during defecation or subsequently in carbonation. Free alkali or alkaline carbonates are not present at all in such juices, and the alkalinity which must finally be retained by them is occasioned not by the true alkalies but by ammonia, organic bases, or free lime. If the decomposition of the invert-sugar, amides, albumins, etc., be not completed by defecating juices of this nature, later on the juice may react neutral or even acid. To avoid this the saturation (carbonatation) of the thin juice in such cases must not be carried so far as to remove free lime completely, for the decomposition is effected in the desired way during the subsequent operations and the lime eventually unites with the acids set free. Such juices are, therefore, always rich in lime salts.

As far as can be done, all possible decomposition of the non-

sugars by lime should take place during defecation. It is entirely impossible, however, to complete this decomposition at this latter stage, because some of these substances, chiefly the amides and bodies similar to the albumins, decompose altogether too slowly under the conditions prevailing at this point, also because it is not advisable, and indeed dangerous, to lengthen out the defecation too much, or to maintain a high temperature, unless one wishes to risk redissolving certain of the precipitated non-sugars. Furthermore, the conditions prevailing during the evaporation are so favorable for the completion of these decompositions, as will be shown later on, that it would be bad practice to carry out the defecation in any other way than that giving proper precipitation of the insoluble matter and consequent easy carbonatation.

With regard to the **most favorable temperature for defecation,** experience has shown this to be between 70° and 80° C. (158°–176° F.) for normal beets.

Cold defecation has been tried and recommended on the assumption that lime at high temperatures decomposes a portion of the precipitated substances, bringing them into solution again. However, proof of this assumption is lacking; many experiments, on the contrary, showing that there is practically no difference between hot and cold defecated juice in case the latter is heated after it comes from the filter-presses, and as long as the action of the lime takes place within the limits employed in practice. Cold defecation should not be introduced into the industry, because the scums cannot be filtered quickly enough even when infusorial earth or a similar substance is added.

Temperatures above 90° C. (194° F.), or even the boiling-temperature, are not to be advised for defecation. Only when beets are of bad quality and contain considerable invert-sugar and other substances decomposable by lime, do high temperatures exert a favorable effect, although even then long boiling, or even boiling at all, should be avoided, because it is likely to cause precipitated substances to redissolve. The opinion that defecated juice which has been boiled up yields scums which can be more readily filtered off is not confirmed; on the other hand it is difficult to saturate boiling-hot juice with gas and the scums hold back sugar.

The duration of the defecation must be kept within certain definite limits. At the relatively low temperatures of from 70° to 80° C. (158° to 176° F.) about fifteen minutes is the proper length of time, while at higher temperatures five to ten minutes is sufficient.

The amount of lime deemed necessary in different factories varies between wide limits. For neutralization of raw-beet juice and precipitation of those substances which lime will throw down, only about 0.15 to 0.20 per cent. of lime, reckoned upon the amount of juice, is necessary. True defecation, that is, one in which the scums are readily deposited, leaving a clear supernatant juice, is obtained by adding from ½ to ¾ per cent. of lime, but with this amount it is not possible satisfactorily to complete the process, since the sludge thus obtained will filter very slowly. A juice which will filter satisfactorily is obtained by the addition of from 1¼ to 2 per cent. of lime.

The addition of a small amount of "Kieselguhr" (diatomaceous earth) before defecation assists the precipitation of the albumins, so that only about 1 per cent. of lime is necessary for obtaining a juice that filters easily. Apparently the kieselguhr acts mechanically only, making the scums more porous, just as do other absorbent materials, such as brick dust, which also economize the amount of lime necessary for defecation, when the beets are of good quality. Whether such addition pays depends on the cost of the material compared with that of the lime saved.

However, in many factories where this amount is accepted as a minimum, it is not considered adequate and 2½ to 3 per cent. or more lime is added with the feeling that in this way a better purification of the juice is obtained. It is certainly true that where larger amounts of lime are employed juices of lighter color are obtained which also contain less dissolved calcium salts; but with regard to the actual purity of the juice, up to the present time there has been found to be no perceptible influence in the use of a smaller or larger quantity of lime. Moreover, the decomposition of the substances which are acted upon by the lime does not take place more rapidly or energetically when an excess of lime is employed because only the

lime that is in solution is active; the amount of lime dissolved depends solely upon the sugar-content and the temperature, and not at all upon the quantity added. For this reason the more or less favorable action resulting from the use of considerable lime is shown not during the defecation, but afterwards, in the carbonatation. Whether the advantages which result there are sufficient to counterbalance the numerous bad effects arising from use of too much lime must be figured out for each particular case. Use of large amounts of lime occasions not only additional expense in providing lime and carbonic acid, but also causes an increased amount of scum and greater losses of sugar retained by them, making more filter-presses and a larger lime-kiln necessary. If it be desired to manufacture a particularly clear juice, as is the case with factories making the finer grades of sugar, then the use of a relatively large amount of lime seems justifiable, but hardly in those factories making ordinary sugar. In working up a particularly bad lot of beets it sometimes seems better to lime strongly in order to improve the working of the filter-presses.

The amount of milk of lime to be added to the raw juice is measured off in ordinary or automatic measuring-tanks. It is highly desirable that the density of the milk of lime should be uniform, and that of 20° Baumé has proved most suitable, for otherwise there is likely to be variation in the amounts of lime added to the juice. In the case of dry defecation the lime should be broken up into lumps of as nearly the same size as possible, which may be either weighed out or measured. While it would seem as if weighing out of the lime would be more accurate, as a matter of fact measuring is preferable, as in this case the influence of badly burnt and consequently heavier lime is not so serious.

Lime should be used fresh, or as soon after it has been burnt as possible, as it then slakes most rapidly. Crumbling which takes place on long standing is caused by formation of calcium hydroxide and carbonate from contact with moisture and carbonic acid in the atmosphere. It will be found necessary to use larger amounts of such lime. It is best to remove fuel-ash as completely as possible from lime which has been in direct contact with the fuel in the kiln, to avoid contaminating the juice.

CHAPTER VIII.

CARBONATATION.

Carbon dioxide, taken from the lime-kilns, is the reagent used for precipitating lime in the defecated juices.

Formerly there was a wide-spread fear that carbonic acid in contact with the scums would act as a solvent of the precipitated matter, based on the fact that a blackening of the juice and scums occurred in supersaturated liquors; that is, in liquors which were treated with carbonic acid till neutral or even slightly acid. Hence those processes were recommended in which carbonatation was made in the clear filtered liquors after the precipitated matter had been removed by filtration. Such procedure is, however, based on incorrect reasoning, as will be made clear later.

It is almost the universal practice now to make the carbonatation on the juice while still mixed with defecated matter and undissolved lime. The defecated juice accordingly goes to the **carbonatation-tank,** which may also serve for the defecator itself, where direct carbonatation of defecated juices is practiced.

Carbonatation-tanks are open or closed, round or rectangular, and usually of considerable depth. In the bottom there are devices for distributing the saturation-gas, as well as heating-coils or steam-injectors.

The simplest and most generally used **distributing devices for carbonatation-gas** are perforated pipes. They distribute the gas exceedingly well, but have the disadvantage that in ordinary conditions of carbonatation the holes become easily clogged, especially if they are small. Since the task of boring out these holes is disagreeable and dangerous for workmen, arrangements have been

devised, particularly for the rectangular pans, to lift out these pipes and replace them. To do away entirely with the labor of this cleaning, distributing-boxes are sometimes used, open at the bottom, with the lower edges notched to facilitate the division of the gas, usually the sides also being perforated. Another arrangement which has been well recommended consists of piping with transverse slits on the under side which are always kept open by revolving scrapers.

The absorption of the carbonic dioxide from the saturation-gas depends not only on the size of the gas bubbles, but on the depth of liquor through which the gas passes and especially on the alkalinity. For more intimate mixture of gas and juice, turbines and stirrers on the principle of injectors, as well as paddles which keep the juice in motion and divide up the bubbles, have proved efficient in practice. Experience has not yet shown that such devices made notable improvement in the process. With all such gas-distributors, the amount of absorption and consequent speed of saturation depends on the alkalinity of the juice. The absorption of carbon dioxide down to an alkalinity of 0.15 to 0.18 does not vary much, but below that point it falls off in quite rapidly increasing ratio. This is well shown in the continuous carbonatation process shortly to be described; in the first tank, where the alkalinity was 0.15 to 0.20 in one instance, 50 to 70 per cent. of the carbon dioxide introduced was utilized, while in the second tank, where the alkalinity was 0.08 to 0.10, only 50 to 55 per cent. was utilized. The second carbonatation, with an alkalinity of 0.04 to 0.05, utilized 45 to 50 per cent.

Evidently a considerable proportion of the carbon dioxide is lost. A suggestion has been made to atomize the juice into the kiln-gases so as to better economize the carbon dioxide, but this idea, which is in itself good, has never been put in practice, since the juice-atomizer would clog up. It is feasible, however, to again utilize the gases escaping from the tank, which still hold 12 to 15 per cent. or more of carbon dioxide, sucking them out by a pump or steam siphon and forcing them through the juice, a separate tank of course being necessary. As a rule there is no neces-

sity of better economy in the use of the carbon dioxide, for every factory which burns its own lime always has an excess of gas.

The temperature of the gas has little influence on its absorption; it appears that higher temperatures are more favorable.

The temperature of the juice falls during carbonatation, partly because steam is carried off by the escaping gas, and partly because the gases themselves absorb heat. This heat loss is made up to some extent by the heat of formation of calcium carbonate from the hydrate, being 330 heat-units (calories) for every kilogram of calcium oxide (1 lb. = 594 B.T.U.). This heat loss is greater in proportion to the temperature of the juice and the poorer the gases are in carbon dioxide and the more lime there is to saturate, since more gas must be passed through. Usually, the temperature drop of the juice can be taken as 5°–6° C. (9°–14° F.), when the lining is 2 per cent., the juice temperature 80° C. (176° F.), and the carbon-dioxide content of the gases 25–30 per cent.

Steam-coils are not suited for **heating defecated juices** in carbonatation-tanks, as they tend to become quickly covered with scale and thus inefficient. This scaling is not usually a result of the routine of the saturation process, but of the interruptions of the work, and this is also true of the clogging of the gas-distributors. When a tank is emptied for shutting down, some scum always remains on the coils or in the holes of the gas-distributors. It dries there or burns on, and thus forms a thick scale in such places. If it be necessary to heat up the juice in these tanks, steam-injectors should be used. Usually heating of juices before carbonatation is to be avoided, as already pointed out, while, on the other hand, bringing the completely saturated liquors to high temperature is decidedly advantageous. In order to prevent dilution, which would result from heating with steam-injectors, and likewise to utilize the low-cost steam from the evaporators, it is advisable to pump the juice out of the tank through a closed tubular heater which has a temperature of at least 100° C. No scale on the tubes is to be feared if the defecated juice enters the heater from above and goes out at

the bottom, and provided the heater is always kept full while in in use.

As stated above, the **depth of liquor** in the tank must be as great as possible to utilize the carbon dioxide most efficiently, but obviously not so great as to prevent the gas-pump from overcoming the back pressure. Likewise the sides of the tank should extend above the liquor-level to a considerable height, at least 3 meters (10 feet), better, 4–5 meters (13–16 feet), so that there will be sufficient room for foam formed during the saturation process.

High sides to the tank, giving plenty of space, afford the best way to prevent foaming over; the more the air-space the less necessary becomes other preventives, such as foam-preventers and application of grease. Foam-preventers use considerable direct steam and dilute the juice. The use of grease and oils likewise costs some money, not to mention the fact that it puts undesirable impurities in the juice, or may be the cause of trouble in the scum-presses, unsaponifiable oils in particular being causes of bad filtration. Nevertheless the use of a small quantity of oil or grease cannot always be avoided. In such cases choose those of greatest viscosity, such as tallow or castor-oil, because a very small quantity of these will do and devices to control the amount added can be made of convenient size. A useful contrivance is a large cask with a gauge-glass from which the oil can be pumped or forced over to the tank through piping. Pressure can be conveniently obtained by a connection from the gas-pump.

The spent gases from the carbonatation-tanks are removed by an exit-pipe of large diameter which allows any entrained foam to drop back. Sometimes there is an enlarged section in this pipe which acts as a juice-trap. If every tank is not equipped with its special exit-flue leading to the open air, that is, when there is only one common exit-pipe for several tanks, care should be taken to have devices to prevent foam from one pan getting into another, for unsaturated juice getting into a tank in which saturation is complete would make the scums filter badly and slime up the filter-presses.

The best way is to have the exit-pipes from each tank lead up into a common collecting-pipe from which the entrained juice runs down into some tank which has recently been filled. A gas-collector is placed in this exit-pipe so that tests can be made of the contents of carbon dioxide in the escaping gases.

Almost universally the saturation-gas is forced into the juice by **pumps.** These pumps are not power-driven, but are always equipped with independent steam-cylinders, so that the stroke can be regulated according to the demand for carbon dioxide. There is little to recommend in steam-injectors, which were used for a time, since they require a large amount of steam, heat up and dilute the juice excessively, and cannot overcome any considerable back pressure. As auxiliaries to help out during pump repairs they are useful.

The **carbonatation of the defecated juice** requires the greatest attention on the part of the workman in charge, for a poorly conducted or slow saturation injures the juice and makes great trouble in the filter-presses later. The duties of the man in charge of the carbonatation are just as responsible, therefore, as those of the batteryman, especially if the original quality of the juice is bad. Where the defecation-plant is independent the man in charge of the saturation must often ascertain whether the juice is properly defecated before applying the gas. The spoon tests should show a deposit readily separating and leaving the supernatant juice clear. In the dry-defecation process the filtrate should show an alkalinity of 0.25–0.35, according to the temperature of the juice; in defecation with milk of lime, somewhat less.

As soon as the carbonatation-tank is filled to the proper depth the gas-valve is opened, only a little at first, because in the beginning the juice foams badly. Since, however, the pump is working continuously, in order to better utilize the gas, not only the valve to one tank is opened, but to two or three tanks, and in such a way that the most saturated tank whose juice foams the least gets the most gas, and the others less accordingly. For this procedure it is necessary to keep all the tanks equally filled with juice. If it were not so, the heavier flow of gas would be into the least filled

tanks in spite of the partially closed valves, since the back pressure would be less, and hence these tanks would be completely saturated before the others although the latter might have stood longer. Systematic supervision and regulation of the carbonatation process would thus be impossible.

The man in charge takes frequent spoon tests during the conduct of the saturation and observes the separation of the precipitate. In open tanks the tests are taken with a long-handled spoon or with a small syringe; in closed pans where the workman stands under the pan the test is taken from a cock. Well-trained workmen can make quite satisfactory saturations by following this test; in many factories workmen go by other signs, as, for instance, the sound made by the gas-bubbles.

The **behavior of the juice in the carbonatation process,** as far as outward appearances go, is as follows: As soon as the gas begins to flow the defecated juice begins to thicken in proportion to its sugar-content; raw juice, however, not thickening perceptibly. The spoon test shows a gelatinous precipitate no longer separating out. The result of this gelatinous condition is the heavy foam already mentioned as occurring at the beginning of saturation, and there is a loud noise made by the passage of the gas. Filtration of the juice at this stage is quite impossible; if this juice by chance or carelessness gets to the scum-presses, the cloths are immediately slimed up. As more gas is passed in, the gelatinous state of the juice entirely disappears, the gas enters more evenly and in smaller and smaller bubbles as the juice becomes more fluid, the foaming ceases entirely, and finally a juice is obtained out of which the precipitate again subsides readily and quickly and is easily removed by filtration.

During this saturation the alkalinity obviously diminishes, but not with any regularity. In the beginning it diminishes quite quickly, from 0.25–0.35 to about 0.15–0.18. At this point it remains almost unchanged, because now about the same amount of lime redissolves as is precipitated by the carbonic acid. When all of the lime has been acted upon, the alkalinity sinks rapidly to 0.06–0.10; hence this value determines the completion of the first saturation,

being the stage when the juice is in best condition and easily filtered. Just at the completion of the carbonatation the man in charge must take great care not to oversaturate the juice.

In every house where special dependence is put on the chemical control, titrations are made from every tank at completion of the saturation, to make sure that juice of proper and uniform alkalinity is sent to the filter-presses, the spoon test being used merely for a rough preliminary determination of the saturation-point. The most desirable final alkalinity value varies, according to the condition and composition of the juice, between 0.06–0.10 per cent. of lime, with phenolphthalein used as an indicator, or 0.09–0.12 per cent., using rosolic acid.

The chemical reactions in the carbonatation process are not yet fully explained. By the introduction of carbonic acid, not only calcium carbonate is formed, but also a double salt of calcium carbonate, calcium sucrate, and possibly caustic lime. This latter compound forms the gelatinous precipitate which contains considerable sugar in the form of lime sucrates. This is more copious and thickens the juice more, the colder the carbonatation is carried out and the greater the sugar-content; although other conditions, as yet unknown, have marked influence on the amount and constitution of these compounds.

These compounds are partially decomposed by the heat and dilution, further treatment with carbonic acid breaking them up completely. As the saturation progresses, the amount of double salts which were first formed continually diminishes, and finally, if the alkalinity is brought down to the proper limit, they usually disappear. In many cases, however, this decomposition is incomplete, so that small quantities of these double compounds remain in the scum and cause increased sugar-loss.

Aside from those reactions of the carbonatation process which are necessarily connected with the neutralization of the lime, there are other side reactions, some favorable, some objectionable. A favorable reaction is the precipitation, along with the calcium carbonate, if only to a slight extent, of those lime salts soluble in the alkaline juice. This precipitation also can only be attributed

to the formation of double salts, and in fact more lime salts will be carried down in proportion as more lime was used in defecation.

Another consequence of saturation is the coagulation of the soft, slimy, flocculent, organic or inorganic precipitates previously formed in the defecation which separate out with the calcium carbonate. The separation of the calcium carbonate does not take place immediately by itself, but requires time, although the period is brief. The precipitate forms more readily and quickly if minute particles are present for it to collect on, and the little particles of slime in the juice answer this purpose. These light particles, which by themselves would filter out only slowly and poorly, become surrounded wholly or in part with an envelope of calcium carbonate, and thereby lose, to a greater or lesser degree, their slimy or gelatinous nature and so can be filtered off much more easily. Therefore, carbonatated juices always filter better than those only defecated, even if these latter are mixed with calcium carbonate, infusorial earth, etc., because such mixing cannot effect the coagulation which results from the saturation.

There is an unfavorable reaction which occurs at times during the course of the carbonatation and causes an appreciable amount of sugar to be retained by the scums even when the process is completed under normal conditions.

The amount of **insoluble lime sucrate** retained by the precipitate, or scums, is usually dependent upon the following: (1) lime sucrate is deposited during defection due to local overheating of the juice or from too much heat after the lime is added; (2) a portion of the lime sucrate which is in the form of double compounds at the beginning of the saturation remains undissolved at the end of the process; (3) lime sucrate is thrown out with the other insoluble lime salts, precipitated either by defecation or carbonatation. The amount of lime sucrate which separates out and remains in the scums is usually exceedingly small, but under unfavorable conditions, as when the three causes above enumerated act together, it may become significant. The result of such sucrate precipitation is a high sugar-content of filter-press cake, which can only be lowered by a tedious sweetening off,

and a lowering of the purity of the juice, for by insufficient sweetening off there is less sugar for an equal amount of non-sugar, while if the sweetening off is prolonged, proportionally more non-sugar is dissolved out of the cake.

If the amount of sucrates precipitated is excessive, and if, therefore, the filter-cake does not permit a ready sweetening off, one should try to remedy the evil by reducing the alkalinity as far as practicable; but since the insoluble sucrate will surely be decomposed in juices free from caustic lime, it is advisable to **oversaturate** the defecated juice if the scums from the filter-presses do not sweeten off easily, which means that not only the lime alkalinity is partly or wholly removed, but also any free alkali. Juice and scums then have a dark, almost black, objectionable color. The scums no longer settle well and the supernatant juice is turbid. Such an oversaturated juice will, therefore, not filter in this condition. If, however, some milk of lime, or freshly defecated juice, is mixed with this oversaturated liquor, so that the alkalinity rises to at least 0.10, the mixture becomes, as far as external behavior goes, identical with saturated juice of the same alkalinity.

Oversaturation without doubt makes a worse juice, for the action of the carbonic acid on juices free from caustic lime, or even entirely neutral or weakly acid, is to redissolve organic non-sugars as well as precipitated lime salts and coloring matters. Whether by the mixture of supersaturated juice with milk of lime or defecated juice all dissolved non-sugars are again precipitated is unknown. Apparently they are, since in practice no difference can be detected in the behavior of such juice from that of juice saturated according to the correct procedure, providing the juice is not too much oversaturated and if, finally, enough lime is again added to make the mixture show more than 0.10 alkalinity, and a subsequent short additional saturation.

The saturation as ordinarily conducted, namely, that of treating each tank by itself, has now been described. Since a continuous process always has certain advantages, in past years many experiments have been tried in this direction. These experiments, which were attempts to produce a **continuous carbonatation** by means of

forcing the defecated juice, mixed with the saturation-gas, through curved pipes in order better to utilize the carbonic acid by an immediate and intimate mixture of juice and gas, have failed owing to the impossibility of maintaining a uniform alkalinity; sometimes the juice would come out from the exit-pipe undersaturated, sometimes oversaturated. It is clear that for the maintenance of constant alkalinity varying proportions of juice must be continually taken in actual practice, since the amount of carbonic dioxide in the saturation-gas, as well as the quantity of lime in the juice, changes to a marked degree. Therefore, best results are obtained by a continuous process of the simplest description: treating the defecated juice in an ordinary carbonatation-tank fitted with a good gas-distributing apparatus and introducing at the same time the appropriate amount of gas. Since the saturation-gas flows in continuously, perforated tubes can be used for distributors, for under these conditions the holes will not stop up easily. A convenient distributing-apparatus consists of a horizontal cross of piping, the arms of which are perforated all on the same side. The gas as it blows in rotates the contents of the tank, producing an excellent distribution of the bubbles and a high economy of carbonic acid. From this first tank the almost completely saturated juice goes up through a pipe out from the top into the bottom of a second tank, in which it is again treated with sufficient carbon dioxide to give the proper alkalinity. It is pumped out of this tank, or preferably from a third tank into which it overflows in proportion to the amount treated. This last tank should be equipped with a heater. By careful regulation of the inflow of juice and introduction of saturation-gas one can count on a very even and effective carbonatation by this method.

Automatic control of the inflow of the juice is very advantageous, and often essential for successful work. This is done by having the juice from the second tank pass on its way to the scum-pump through a decantation-tank provided with a ball-cock. If more juice goes into the decantation-tank than passes out, the float, acting on a lever, rises and shuts a throttle-valve in the pipe-line discharging into the first saturation-pan. This throttle shuts when

the float reaches its highest level, and again opens when the pump has taken away sufficient juice. The man in charge, therefore, need not trouble himself with the juice-feed, but can devote his whole attention to the carbonatation and can carry this to the proper point, being guided in the regulation of the gas-valve by the indications of titrations, which should be made frequently. It is necessary to titrate the juice of the second tank only, in the first tank merely taking care that the juice is not completely saturated. Often only one saturation-tank is used. Aside from the disadvantage that working in this way there is more uncercertainty of holding the alkalinity constant, the utilization of the carbon dioxide is very inefficient. If two tanks are used the alkalinity in the first is 0.15–0.18, and in the second 0.07–0.10. In this case, the major part of the gas passes through juice of an alkalinity of 0.15–0.18, which is notably higher than that of second tank. Using only one tank with a continuous carbonatation, the alkalinity must be kept always at 0.06–0.10. Hence, the gas passing through juice of such low alkalinity will be very inefficiently utilized, as we have shown previously.

The chemical reactions occurring in continuous carbonatation are somewhat different than in the ordinary method, because the first pan always contains a fairly well-saturated juice. The freshly defecated juice is always mixing in with such liquor, so that the definite stages of chemical change noted in carbonatating a single tank do not here appear. Little or no gelatinous double salts are formed, hence the carbonatation goes quicker and more regularly. Since quick carbonatation is best for the juice, this continuous method of working has advantages over the ordinary process. These advantages, however, are not obtained unless the defecation is conducted with even more care than in the usual process, since defecated juice entering the first tank stops the action of the lime.

Carbonic acid is practically the universal reagent used for neutralizing lime. Experiments have been tried of using carbonic dioxide first and completing the saturation with sulphurous acid, which gives clearer and better juices. However, the out-

come of these investigations is that it is seldom advisable to use such procedure, since it increases the cost of carbonatation and makes its supervision more difficult.

Carbonatation troubles are usually shown by the process going too slowly. There are many causes for this. Since gas rich in carbon dioxide is the prime requisite for good carbonatation, it is obvious that from gas of such quality more carbonic acid will be absorbed, not only absolutely, but relatively. It is necessary on the other hand, to introduce the required amount of carbonic-acid gas into the juices. If the carbonic-acid pump is too small or is defective in its action, the carbonatation will always be insufficient. The size of the pump's cylinder should be large enough so that under normal conditions a relatively slow stroke is sufficient, and when there is a leakage in casing, valves, or pipes it can be compensated by quickening the stroke. The amount of carbonic-acid gas, or the efficiency of the pump is diminished if the exhaustion in the suction-pipe is too great. There is always some vacuum in the suction-pipe owing to the resistance in the tube itself and in the washers, but this should never be more than is equivalent to a water-column of about 3 feet. In order to measure it, and to find readily any place where there is too much resistance, it is well to insert water-column vacuum-gauges before and behind each washer as well as at the pump. It is then immediately apparent whether the greater resistance is caused by irregular working of the washers or by the stopping up of the piping by flue-cinders from the lime-kilns.

Too slow carbonatation, or rather a lengthening of the duration of the process, will take place when too much lime has been added to the juice; this is likely to be the case when the milk of lime has been made too thick or too much dry lime has been added.

Besides these causes of slow carbonatation which can be easily explained or detected, there are others which probably depend to some extent upon the nature of the diffuser-juice and which are much more difficult to explain. It is very probable that in this case, again, the pectic substances exert some influence, because,

when the carbonatation-work is unsatisfactory on account of the quality of the juice, it will be found invariably that this juice was obtained from unripe, over-fertilized, or decayed beets, and results also depend somewhat on the method of carrying out the diffuser-work. These pectic substances when present in large amount appear to combine with the lime and thicken the juice just as the sugar itself does, except that it is more difficult to get rid of this thickening when caused by the former substances, and for this reason the carbonatation process is retarded. In such cases the best preventive is to change the diffuser-work so that the juices are obtained as quickly as possible and at not too high a temperature. In every case where the carbonatation process is lengthened, no matter what the cause may be, the quality of the juice is bound to suffer both in color and purity. For this reason the cause of the slow carbonatation should be removed as soon as possible.

Testing the escaping gases systematically is a great help in locating the cause of slow saturation, especially in continuous carbonatation. By knowing the normal carbon dioxide content of these gases, if poor absorption is the cause of the trouble it is at once detected.

Another undesirable disturbance of the carbonatation process is caused by a strong frothing of the juices. This phenomenon also depends upon the quality of the beets and the method of working the diffuser battery, and occurs usually when there is a poor carbonatation. It is evident, therefore, that both disturbances result from the same cause. When the frothing is so strong that the space above the juice-level is insufficient, the only remedy is to add oil or other fatty substance. In continuous carbonatation the foaming is seldom bad so that little or no oil is needed. Obviously, sugar is lost if foam is carried off through the vent-pipes by the waste gases. Moreover, appreciable quantities of sugar will be found in the escaping vapors even when when the juice does not foam. The results of investigations into these losses are awaited with interest.

CHAPTER IX.

TREATMENT OF THE SLUDGE OR SCUMS.

FROM the carbonatators the juice is pumped to the filter-presses. Juice-lifters (*monte jus*) are no longer much used, on account of many disadvantages, such as uncleanliness, dilution of juice by condensed steam, irregular pressure, and consumption of power. **Scum-pumps** are always constructed of the plunger type, single or double action, and work either with automatic regulation or with a by-pass worked by a sensitive safety-valve. A good stone-eliminator must be connected with the piping through which the juice is drawn to the pump, so that not only stones but also the heavier sand will be removed which would otherwise clog up the pump and close up the narrow canals of the filter-presses. The pressure at which the pumps should operate depends upon the size of the filtering-surface in the presses and the nature of the scums. It is desirable that the pressure should not be too great, say about two or three atmospheres (30 to 45 lbs.), as the cake so formed is most readily exhausted of its sugar. With poor scums and small filtering-surfaces the pressure may be raised to from four to eight atmospheres (60 to 120 lbs.). A pressure higher than this is not permissible on account of danger of the walls of the chambers of the press collapsing if there happen to be more pressure upon one side than the other. In order to keep the pressure under control, manometers, or gauges, must be placed on the force-pipe and on the air-chamber. In the piping back of the pump a gate valve is placed to shut off the juice in the pipes when necessary to overhaul the pump.

Filter-presses are of two types, chamber presses and frame presses. The **chamber presses,** in which the juice-canal is placed in the middle and the cloths are stretched by means of cloth-screws, have the advantage that it is possible to make them

tighter because at the outer joints four layers of cloth come together; whereas they possess the disadvantage of requiring considerable time for drawing over the cloth on account of the screwing arrangement; moreover, in the slack spaces the cloths become jammed and torn. **Frame presses** are usually preferred in which the cloths are placed smoothly over compartments between frames, the filter-press being set up in a few minutes. An objection to this type of press is that there is likely to be some leakage at high pressures, although this ought not to be the case if the workmen are practiced and keep the frames clean and free from adhering sludge, taking care that the cloths lie smoothly during the closing together of the chambers; consequently it is only in the first few weeks of a campaign that the presses do not work right. Another objection is that the cloths wear badly at the upper corners where the chambers and frames are closest, and this is aggravated because the workman always tries to draw the chambers together as hard as possible in order to close up the press well. It is a matter of taste whether rubber or filter-cloth gaskets are used for the joints of the juice-ducts. Both make equally tight joints.

The size of the filter-presses, or the size and number of the compartments and frames, depends upon the amount of work to be done. The presses should have capacity enough to permit continuous work. It would be wrong to use a large press in a small factory, or one large press and several smaller ones, because, in such cases, when the large press is just emptied there will be too much juice at hand for the house to take care of advantageously, while in the other case the juice dams up and the house is blocked when the presses begin to fill up. Again, it is equally foolish to use a lot of little presses in taking care of the juice from a large factory, because many more workmen are necessary and more cloths are worn out than when there are fewer and larger presses.

The size of the chambers or frames varies between six and ten decimeters (24 to 40 inches) square. In a single press, or in one division of a double press, there are between 20 and 40 of these

divisions, and the thickness of the pressed cake is between 15 and 30 mm. (0.6 to 1.2 inches). In the case of bad scums considerable thickness of the cake is undesirable, whereas with good scums that are easy to filter it is well to have a thick cake; as a matter of fact in some factories cakes thicker than 30 mm. are produced.

It is not possible to state definitely just how much filter-surface should be calculated for the daily working up of a definite quantity of beets, because the readiness with which the scums can be filtered varies greatly. It is desirable, however, that as large a filtering-surface as possible should be provided, so that it will be sufficient, even when there is difficulty with the filtration, to keep the factory running at its usual capacity. In this case there will be ample time for a good sweetening-off of readily filtered scums.

During the campaign it is usually unnecessary to **clean** the filter-press ducts and strainers. After every campaign, however, they must be examined and cleaned, since the holes of strainers, the various ducts, and the discharge-cocks become stopped up or contracted by deposits of scale. If these passages cannot be cleaned by brushing and boring out, or when such a procedure proves too tedious, the strainers and frames can be dipped in water containing hydrochloric acid, or concentrated acid must be poured through the canals. In all cases they must be well washed out with water so that all traces of acid are removed, and in order to prevent the strainers from rusting they must be varnished as soon as dry. If there is fear of the acid eating into the strainers too much, use may be made of mechanical flue-scrapers for cleaning out the holes which are clogged. In some factories it is the custom to pump hot water containing hydrochloric acid through the presses immediately at the close of the campaign; this method of cleaning the presses saves considerable time, but should be used only with great caution to avoid injuring pumps, pipes, and different parts of the presses.

The **choice of cloth** for the filters is not without influence upon filter-press work, but here again opinions differ. Whereas in one factory a heavy cloth of as good quality as possible is preferred, in

another a quite light fabric will be used. As a rule for the first carbonatation a material made of jute is used, because it is cheapest and suffers little from the influence of the alkaline juice. With regard to the durability of the cloth, naturally the degree of alkalinity and the temperature of the juice exert considerable influence. When the scums are poor and the cloths must be frequently changed and cleaned, preference should be given to a material which is not too light and of not too poor quality and which washes well. When the scums are as a rule easy to filter, cheaper cloths of lighter fabric are suitable, these being allowed to remain in the presses until worn out—a matter of perhaps fourteen days or longer. It goes without saying that it is important to have the cloths of proper size, so that they will not crease or wrinkle.

In many factories it is customary to avoid changing single cloths in a press, and as a result it is a common error to allow all of the cloths to remain too long, even until the liquid runs through turbid. The cloths throughout the whole of the press are then renewed and replaced by new ones which are all of the same kind and possess equal filtering capacity; either new cloths are used throughout, or washed cloths are placed underneath and new ones on top. In this way the press will be filled uniformly and the sugar washed out equally well from all parts.

Special washing-machines are usually required for washing the cloths. It has proved very satisfactory to place them in a drum provided with compartments; hot water flows continuously through this drum and, while the latter is revolving, the cloths in the compartments partially filled with water are thrown about back and forth. Wetting new cloths before placing them on the presses is unnecessary when jute is used.

In order to give the cloths a good surface to lie against, sheets of perforated metal are screwed on the chambers. Recently the surface of these chamber-plates has been grooved without the sieve. The advantage gained is that the cleaning of the sieve and its wearing out is obviated and the cloths are said to last as long.

The **press-cake** is formed in the presses between the cloths by

the gradual deposition of the scum in uniform layers upon the cloths. The heavier particles of the sludge, such as the coarser sand, sink to the bottom of the section as long as the contents remain soft, and the lower portion of the space between the cloths is filled rather more quickly than the upper part; but, as a general rule, where the pressure from the pumps is not too low the cake is uniformly deposited by the current of liquor flowing through the cloth. This is evident by breaking the cake and observing its differently colored layers. Each tankful of juice gives with the separate carbonatations a somewhat differently colored scum, so that the press-cake will have a layer that is more or less yellow, followed perhaps by one which is bluish in tone. In the case of continuous carbonatation the press-cakes are of uniform color.

When the entrance-valve of an empty filter-press is opened the juice runs in a strong stream from the discharge-cocks. The greater the amount of sludge upon the cloths, the less penetrable they become, so that as the press-cake increases in amount, the slower the filtered juice runs off, and finally at the end of one or two hours the press becomes full and the juice drops from the cocks in very thin streams. The workman in charge must know from experience when the press is sufficiently filled. It is a waste of time to allow a press to work too long, while, on the other hand, a press that is not entirely filled will not permit a satisfactory exhaustion of the sludge, and the soft filter-cake contained in the press readily smears over the cloths and frames, so that subsequently the press is likely to squirt and run badly. Since a good scum-cake, or at least one of relatively firm structure, always facilitates the work of the exhaustion of the residuum, it is advisable always to allow the press to become as full as possible even when it runs slowly. It is not possible to improve matters by emptying the press as soon as it begins to run badly, for the time spent in removing the soft slimy mass, together with such evils as subsequent leakage, smearing the cloths, etc., more than compensates for any gain in the actual time of filtration; it is advisable to calmly wait for the press to become reasonably well filled, so that it will leave a dry press-cake.

The cause of slow-running presses, or in other words of the juice filtering badly and the undesirable, soft consistency of the press-cake, is to be sought either in the nature of the beets or the method of working. It has already been mentioned that in working up certain grades of beets the diffusion-work exerts a great influence upon the consistency of the scum. When the quality of the beets is the cause of the presses clogging, there is some gain to be sought in changing the method of working the diffusion. Increasing the amount of lime added to the juice above a certain limit has seldom met with success, aside from the fact that most factories are unable to take care of sludge much in excess of the ordinary amount. Likewise, slight success is obtained by boiling up the juice, as has been frequently recommended, since there is then greater difficulty in emptying presses and the scum obtained is little, if any, better than that obtained at the usual temperature of from 80° to 90° C.* Similarly changing the alkalinity of the juice is of no use. In short, it is best to avoid all useless experiments and merely try to hasten the work by changing cloths often. These difficulties are met with chiefly at the beginning of the campaign, when it is necessary to work up beets which are not quite ripe and with unpracticed workman, and the trouble as a rule will shortly disappear apparently of its own accord.

A press-cake, difficult to filter and sweeten off, often comes from the diffusion juice of high density, over 15° Brix, especially that from wilted or dried beets. In this case the usual remedy is increasing the size of the juice drawings, which of course causes dilution. Since, however, this increases the work of the evaporator it is better to provide for this dilution by sending all the sweet-water from the filter-presses, not needed for slaking the lime, back to the defecators or carbonatation tanks, whereby the carbonatation will likewise be improved.

From the reactions during carbonatation it is clear, without further explanation, that juices which have been either insufficiently

* 175–195° F.

or too completely saturated with carbonic-acid gas will be difficult to filter. Consequently it is always necessary to conduct the carbonatation with the greatest care, but especially when the sludge itself is of a nature which renders the filtration difficult. When the presses run badly for a temporary period, it may be due to juice from a properly carbonatated tank becoming mixed in pumping with juice from a tank which has not been properly saturated, owing to a leaky valve or by the foaming over from one tank to another. Whether this is the cause of badly filtering scums may be determined by titrating the juice that comes from the press. Such juice will show a considerable higher alkalinity than that coming from single tanks which have been properly carbonatated. It is advisable to make such control titrations at frequent intervals. A slight increase in the alkalinity of the juice is nearly always produced in the filter-presses, because the sludge encloses small amounts of caustic lime and lime sucrate which gradually dissolve throughout the whole layer by the juice that is continually passing through it. This alkalinity amounts, as a rule, to about 0.1 per cent. of lime.

Soft cake is also obtained when the pump does not give high enough pressure, and to guard against this it is absolutely essential that there should be a manometer, or pressure-gauge, in the discharge-pipe.

The **amount of sugar left in unwashed filter-cake** varies according to the amount of sugar in the defecated juice, and to the amount of insoluble lime sucrate formed. Usually the scums are composed of about 40–50 parts of solids and 50–60 parts of juice. If the latter contains 10 to 12 per cent. of sugar, it is evident that the filtered residue will contain from 6 to 7 per cent. of sugar.

The **sweetening-off of the filter-cake** should work so as to remove the greater part of the sugar and make the sweet water from the washing as concentrated as possible. This result can only be attained by driving the juice out of the cake through introducing water into the press itself. In some factories the filter-cake is removed from the press, mashed with a little water, and the mass is then

filtered again in the press. By this method of working, however, a weaker sweet water is obtained, with the same amount of sugar remaining in the cake as when the washing takes place in the press itself. The latter method has the sole advantage that it permits the use of a simpler type of filter-press.

Washing the cake may be done in two ways: either have the water enter through special canals placed on one side of the scum-cake, penetrate the latter and flow away at the other side, or have the water follow the same course as that taken by the original juice, enter through the centre of the cake, pass through both halves and flow away on both sides.

Indispensable conditions upon which the success of either method of washing depends are a uniform nature and thickness of all the scum-cakes in one press and evenly penetrable cloths. When the cake is thinner and softer at one place, for example in the upper part of presses which have been badly filled, more water will penetrate these portions than through the thicker and harder parts. When, therefore, the former portions are already completely sweetened off, the thicker portions are still likely to contain considerable sugar. This trouble becomes more appreciable in proportion to the amount of pressure employed. Certainly this unequal penetration of water into the scum-cake can never be entirely prevented, because, owing to the construction of the presses, even the best and most uniform cakes will have bad places. In the case of the chamber presses these bad spots are at the outer borders where the cakes are thinner, and at the places where the cloths are screwed together, where the scum-cake usually remains soft. In the case of the frame presses these spots are found between the iron frames and the cake, where the adhesion of the latter to the iron is less than the cohesion of the cake itself. Excessive solidity of the cake is also detrimental, because in such cases the solution of the sugar throughout the whole mass takes place slowly and requires greater water-pressure. Consequently every variation in the thickness of the scum-cake then makes itself objectionable to an increased extent.

In order to avoid troubles from variable or excessive pressure,

the scum-pumps in some factories are not allowed to work directly upon the filter-presses. The juice is pumped into a tank placed high and provided with a return-flow pipe. From this tank the juice runs into the presses with the relatively low but always uniform pressure of from one to one and one-half atmospheres.* It is said that under these conditions the presses work better and that it is then much easier to remove the sugar from the filtered residues.

High water-pressure is above all things incompatible with a satisfactory removal of sugar from the cake; but where low pressures are used it takes very much longer to remove the sugar and a larger number of presses is necessary.

Many believe it is better to **operate the pump for sweetening-off at a pressure** slightly higher than that of the scum-pump, and possibly in many cases this rule may work satisfactorily, but it is more correct to adjust the pressure of the sweetening-off pump so that in a given time a definite volume of the sweet-water will be obtained. Consequently the pressure of the latter should be regulated according to the nature of the scum-cake and its thickness, but taking care that this pressure shall not be made too high so that any inequalities in the cakes will make trouble. It may be assumed that the highest pressure for efficient washing with the least water should not exceed about two atmospheres. Every increase of pressure above this point causes increased volume and dilution of the sweet-water and leaves the same amount of sugar in the press-cake.

The **time required for sweetening-off** the cake to 1 per cent. is quite long. With low pressures it can be assumed to be about 20 to 30 minutes with good slimes, and about 100 to 150 parts of sweet-water will be obtained from 100 parts of scum. If the pressure be increased, as must always be the case with poor scums, then the volume of the sweet-water is increased to a considerable extent and the liquid flows much more slowly through the

* 15–22 lbs. per square inch.

press; it is then usually not practicable to reduce the sugar-content to an average of but one per cent. In German factories the extraction is considered satisfactory when the sugar-content is reduced to from 1½–2 per cent.

The question as to whether it is advisable to use hot or cold water for washing the cake has not yet been definitely settled. It is, however, hardly probable that the **temperature of the water** exerts any influence upon the purity of the sweet-water obtained from the presses, provided *pure* water is used. As there are large amounts of pure hot water available in the beet-sugar factory from condensed steam, it is usually best to use it without going to the trouble of cooling. The only advantage to be obtained from using cold water is perhaps that the filtered scums will cool down so that the workmen will be less inconvenienced by steam while discharging the presses. Cold, hard well-water should be avoided as far as possible, for when such water entering the hot compartments comes in contact with the lime contained in the juices, precipitates will be formed that will tend to clog up the ducts and strainer of the press, besides making the cloths stiff. It is true that these lime deposits may be formed when using condensed water in case the latter contains ammomium carbonate instead of ammonia. Ammonium carbonate is formed in large amounts when the juice is over-carbonated in the second carbonatation.

It is evident that so much water used in washing will to some extent redissolve the non-sugars that have been precipitated from the defecated juice, and consequently the last of the sweet-water obtained from the presses, in which the small amount of juice remaining in the sludge has been diluted with a large amount of water, will be of a lower purity than the first. The purity, however, remains sufficient to yield a massecu'te which will readily crystallize. There is, therefore, absolutely no objection to washing the residues thoroughly, provided the number of presses is sufficiently large and it does not make too much dilution.

Which method of washing the residues is to be chosen, i.e., whether the water should be allowed to pass through special ducts in the press and then percolate through the whole cake, or whether

the water should follow the juice-ducts and pass through half of the cake, depends upon particular conditions. In general the former method is preferable with well-arranged presses, because under otherwise similar conditions the cake is more uniformly sweetened off and the juice is less diluted. Special precautions should be taken to see that the juice-valve is tightly closed during sweetening-off and that during filtering the water-valve is well shut. If the former has been left open sweetening-off is impossible; if the water-valve leaks the juice is badly diluted. Unremitting vigilance over these valves is essential.

In those factories where milk of lime is used for defecation the weaker portions of the sweet-water should be collected separately and used for slaking lime. Since for slaking one part of lime from 5–6 parts of water are required, and one part of lime yields about 3½ to 4 parts of sludge, it is evident that in such cases there need be no particular apprehension with regard to excessive dilution of the sweet-water, for an amount for water equal to 150 per cent. of the weight of sludge is necessary for the slaking of the lime. On the other hand, in factories employing dry defecation every unnecessary dilution of the sweet-water is to be avoided, for in such cases there is no especial use for the more dilute portions of it. All of the water must then be worked up with the juice, and if it is diluted too much, the advantage gained from dry defecation, especially with regard to saving of fuel, is lost.

However, a thorough sweetening-off of the scums from the dry-defecation process without thinning the juice excessively has been proposed in which the *sweet-waters are separated* according to their density. The first sweet-water which is rich in sugar goes as usual to the juice, but the later water is cut out and utilized for sweetening-off the next press, and so on. Appropriate devices make this system automatic.

The **cake** that is emptied from the presses falls either into cars (by means of which it is carried out and deposited in heaps), into a screw conveyor, or into a scum-mixer in which it is mashed into a thick paste. The paste can then be flushed out with waste water

of the factory, or be carried to any desirable place by means of pumps. Cakes obtained by the use of a minimum amount of lime make the most desirable fertilizers, because the amounts of phosphorus and nitrogen contained in them are relatively higher than in cakes with an excessive amount of lime.

CHAPTER X.

FINAL CARBONATATION AND FILTRATION.

THE juice from the scum-presses is sent to the tanks for a second carbonatation. Since this juice has become cooled in passing through the filter-presses and canals, it must be **reheated,** exhaust-steam reheaters being obviously best suited for the purpose. This reheating should be carried to boiling temperature, since it is important that thin juice should be kept at about 100° (212° F.) after the first filtration. This high temperature is not only desirable for the action of lime on the non-sugars, but it is necessary to prevent the calcium carbonate formed in the second and third carbonatations from going into solution as acid carbonate.

If lime is added in the second carbonatation the heating must take place first, to avoid heating with excess of l me, since some lime sucrate is precipitated out of juice saturated with lime at 70°–80° (158°–176° F.) when such juice is heated to 100°. Usually about 0.25% of milk of lime is added to the juice before the second carbonatation, but such **addition of lime** is generally of no perceptible use, since the lime still in solution at this high temperature serves to carry on the decomposition of the non-sugars. When dry defecation is used for the first carbonatation, this second addition of lime is entirely omitted to avoid preparing milk of lime especially for this purpose; putting dry lime directly into the hot juice would make conditions favorable for forming much insoluble sucrate and consequently is not advisable.

The **second carbonatation** can be carried out most conveniently as a continuous process and by using three tanks, or two, arranged so

that the juice overflows from one to the other, one heater being used. The juice is heated to the proper temperature in the heater and flows into the first tank, where it is saturated with gas, usually after lime has been added; after flowing over into the second tank it is pumped off. A third carbonatation is carried out like the second, the most important condition being that the same high temperature is maintained.

Where only one after-carbonatation is made, it is either done with carbonic acid alone or together with sulphurous acid. When two after-carbonatations are made, in the first only carbonic acid is used, in the second carbonic acid alone, sulphurous acid alone, or both together.

There has been much dispute whether **one or two after-carbonatations** should be used. It is not to be denied that the alkalinity can be more carefully regulated and any injurious influence of excessive carbonatation on the precipitates be more easily avoided by two carbonatations rather than one.

Two saturation-plants, however, make the work slower and require more supervision. Many factories do well with *one* final carbonatation.

A second after-carbonatation must always be made if the juice to be treated contains magnesia. **Magnesia** always goes into solution if the juice is gased so that the alkalinity falls below 0.05, apparently forming an ammonium-magnesium carbonate, or a double carbonate which decomposes during the evaporation of the juice, forming insoluble magnesium carbonate. In such cases the alkalinity of the second carbonatation-juice (in the *first* after-carbonatation) must be kept above 0.05 per cent., the proper alkalinity not being made till the juice is filtered.

There is a great deal of dispute also **as to how alkaline** the thin juice should be made. Some recommend a high alkalinity, others a carbonatation almost to neutrality. To answer the question properly, the behavior of alkaline and neutral juice during evaporation should be studied, as well as that of the non-sugars precipitable during carbonatation in juice of different concentrations.

If thin juice is saturated with sulphurous acid to the neutral

point, no doubt it has a brighter color than alkaline juice, but the color of the juice, especially that of thin juice, which in the course of the process of sugar-making can, and actually does, alter very much, cannot be taken as a standard for guidance in treating such juice.

During evaporation juice in practically all sugar-houses is exposed for some time to temperatures over 100° (212° F.), the temperature of the juice-heaters in many houses rising as high as 115° (239° F.) or even to 120° (248° F.), and likewise it is at more than 100° in the first vessel of the multiple-effect apparatus. It is very doubtful whether neutral or weakly alkaline juices should be exposed to such high temperatures, for the alkalinity is continually becoming less during evaporation. Consequently neutral juices almost invariably become faintly acid and a noticeable inversion takes place, which is evident by the darkening of the juice. Juices of proper alkalinity, on the contrary, suffer no perceptible decomposition during evaporation if the temperature does not exceed the familiar limit of 115°–120° (239°–248° F.), but they are even improved by this high temperature, as the alkalies act energetically on the non-sugars which are not thoroughly decomposed in defecation, such as amides and albumens. Such alkaline juices as a rule also show a noticeable falling off of the alkalinity, but it does not reach neutrality, and it is not caused by decomposition of sugar, but by combinations of acids formed from the non-sugars with the alkalies, or on account of the escape of ammonia either previously present or just produced by these reactions. Hence that process is completed during evaporation which would have taken place in the strongly alkaline and defecated juice if the necessary time and space had been available.

Without anticipating the question of making the sirup from the evaporators strongly or weakly carbonated, it should be settled now as to whether it is better to remove the last portions of lime carbonates and sulphites from the thin liquor or from the sirup. The deciding point is the relative solubilities of these substances in sugar solutions, for a thorough carbonatation of the thin liquor can be advantageous only provided these lime salts are less soluble

in thin juice than in sirup. It happens that almost all of the difficulty soluble lime salts are less soluble in concentrated sugar solutions than in the more dilute, and during evaporation of the thin juice the carbonates, sulphites, and other lime salts are continually depositing on the heating-tubes of the evaporating-apparatus, irrespective of whether the thin juice is neutral or alkaline.

All considerations, therefore, are in favor of an alkaline juice, and one so alkaline that the uncarbonatated intermediate sirup, or "mittelsaft," is still alkaline. Hence it is not good practice to prescribe a certain fixed alkalinity for the thin liquor; this alkalinity should vary much according to the characteristics of the juice and its behavior in evaporation, but it is possible to set upper and lower limits to this variation. The upper limit will be that alkalinity due to the free lime and sucrate present; the lower limit must be set with reference to the alkalinity of the uncarbonated intermediate sirup, or "mittelsaft." If a certain fixed value has been found suitable (say 0.05–0.10 or thereabouts), the alkalinity of the thin liquor must be raised or lowered accordingly as the alkalinity of the sirup begins to sink under normal or as it becomes too alkaline. Ordinarily when the alkalinity of the juice is 0.03 to 0.05 per cent., as indicated by phenolphthaleïn, very little or no lime is present in the caustic state (usually being in combination as salts). The most of the alkalinity, therefore, is caused by fixed alkalies, organic bases, and ammonia. If the composition of the juice makes necessary an energetic after-treatment of alkalies or free lime in the evaporators, as when working up unripe or rotten beets, the highest suitable limit should be set for the alkalinity of juice and sirup. Obviously in such cases the fact should also be taken into consideration that strongly alkaline juice will form a heavy scale in the evaporators; hence, if the evaporation is much retarded by this, the alkalinity should be lowered.

As far as the purity and good working qualities of the juice are concerned, it makes no difference, in working at the final high alkalinity as recommended, whether the final carbonatation is completed with carbonic or sulphurous acid. Carbonic acid has

the advantage of simplicity and cheapness, saving the sulphurous acid for the finished sirup or the "mittelsaft."

If two final carbonatations are considered expedient, the alkalinity of the first should be about 0.01–0.02 per cent. higher than that of the thin juice, so that in the second carbonatation there will remain some work for the gas.

Whether two carbonatations or only one is made, **a double filtration of the thin juice** must always follow to insure absolutely clear juice for evaporation. Filter-presses are usually employed for the first filtration, with cloths of closely woven cotton flannel, jute, or linen. For this filtration it is better to use filter-presses without sweetening-off passages, because such passages have the disadvantage that if the juice runs turbid from a discharge-cock, there is no means of shutting off the chamber which is filtering badly. If the cock is closed, the cloudy juice will run through the sweetening-off passage into other chambers and make them run turbid.

This simple type of press naturally can only be sweetened off through the scum-openings, but usually it is decidedly inadvisable to sweeten off second carbonatation-scums. If no lime is added, the amount of cake is very small, scarcely 0.1% of the beets, so that the sugar loss, even if the sugar in the cake is considerable, is hardly worth taking into account. If, owing to addition of lime, there is a larger amount of cake, it is better to send it to the first carbonatation-tanks than try to sweeten off in the second filter-presses. It suffices to give these latter a simple steaming.

The sugar-content of the filter-cake, unsweetened but steamed out, is usually high, between 4 and 7 per cent., because almost always it contains insoluble calcium sucrate. The filtration after the second carbonatation usually presents no difficulties, so that a small filtering-surface is sufficient. Once in a while the presses suddenly begin to run badly or filter slowly, complete cakes are not formed, and a small amount of stickier scum appears on the cloths. This trouble comes ordinarily when the first carbonatation has a badly filtering scum, and is an especial characteristic of too much gas in the first carbonatation. Magnesium carbonate then goes into solution, as already stated, this again separating in the

second carbonatation. The magnesium carbonate so precipitated, as well as the other magnesium salts which separate out of solution, are always of a slimy nature and make filtration more difficult the greater their proportion to the calcium carbonate present.

Filter-presses are less suited for the second filtration of thin juices. Usually the **improved form of bag filters** or **a filter apparatus** having the maximum filtering-surface in the least space and permitting filtration under minimum pressure is employed. Low pressure is vital for retaining the more minute scum-particles in the cloth. What advantage one make of apparatus has over another depends on its convenience for changing cloths and the retentiveness of the cloths or bags.

A very good and reliable filtration can be made with gravel, coarse sand, or similar fine-grained substance, in filters like those in which bone-black is used, or in sand filters of special construction. These latter filters should be so built as to require no hand labor for washing the sand either in the filter or in special apparatus. Filtering through fragments of cork, the juice entering at the bottom and forcing its way upward through the cork, which floats in the upper part of the filter, is scarcely used now, nor is filtering through wood chips and excelsior.

All these filters work well if handled intelligently, providing the juice holds little scum. They are unsuitable for treating any large amount. The customary methods, using filter-presses, are worth most consideration.

Often something is added to the thin juice (and later to the thick juice) to increase the efficiency of the filters by coagulating the finer scum-particles, particularly those which quickly slime up the cloths. Sawdust, cellulose, and infusorial earth are suitable for this purpose. Care must be taken that these materials are pure and do not neutralize weakly alkaline juices. In certain cases they must be first digested with soda lye to purify them; as a rule this addition of material is considered unnecessary.

Two canals should be provided for every thin-liquor filter, one for carrying the perfectly clear juice flowing to the evaporators, the other for taking the cloudy juice, which runs off particularly at the start of the filters, back to the second carbonatation-tanks.

CHAPTER XI.

OTHER PURIFYING AND CLARIFYING AGENTS.

BESIDES lime and carbonic acid or sulphurous acid, many other agents have been recommended for purifying, decolorizing, and clarifying the juice. A list of the different substances tried would amount to approximately 300; of which number 40 are made up of the different sulphur acids and their salts, 25 are the phosphorus acids and their compounds, 23 are the different organic acids and their salts, 47 are alkalies, alkaline earths and their compounds, 69 are metals and metallic salts, 56 are organic substances, and 15 are substances prepared electrolytically.

These agents have been used partly in the diffusion battery, partly upon the crude juice in the defecation, and upon both thin juice and sirup. In practice none of these different chemicals have continued in use. Disregarding the majority of the recommendations, which are senseless, it can be said that whereas in certain directions many of these chemicals are actually efficient, their use would be limited to certain definite conditions, and in the majority of cases they are altogether too expensive in proportion to their efficiency. In certain cases poisonous substances would be introduced into the juice which, even if not detected in the sugar, would be present in the molasses, making it worthless as cattle-fodder.

Since there is no object in purifying diffusion-juice previous to defecation, any purifying agent should show its action chiefly where the non-sugars, upon which it would be supposed to act, are present in the largest amount, namely, in the molasses. As a matter of fact most of the agents recommended have shown themselves to be either without any purifying action, or else the action is so slight that the chemicals are too expensive to use.

Only relatively few substances could be used to advantage with

certain thin or thick juices. Of such substances the most efficient are the carbonates and acid sulphites of the alkalies, or caustic alkalies which transform the excessive amounts of organic lime salts into the corresponding alkali salts, and phosphoric acid which precipitates lime as calcium phosphate. Baryta is used to effect the precipitation of sulphurous and certain organic acids; both it and barium chloride are said to exert a favorable influence upon the crystallization of the sugar. Magnesia, to which favorable action was attributed at one time, is inferior to lime both with respect to the juice-purification and the filtration of the scums, without having other advantage. Alumina acts as a clarifying agent and produces a clear juice; tannin precipitates albumins to the extent that they are present in the juice; and cinders, lignite and charcoal clarify the juice without purifying it. As decolorizing agents, besides sulphurous acid, there should be mentioned hydrosulphurous acid and ozone with or without simultaneous application of bone-char powder. Recently, commercial hydrosulphites have been introduced, especially sodium and calcium hydrosulphites. They bleach juices even if they are alkaline, their action on the natural coloring matters being very marked, although they do not affect the characteristic caramel color resulting from the decomposition of sucrose and invert sugar. The hydrosulphites are especially efficient if introduced in the vacuum pan, because here the objectionable return of the dark color from oxidation of the air is prevented. 0.01 part of hydrosulphite for 100 parts of sugar. Furthermore, the salts of the heavy metals, particularly those of zinc, tin, and lead, effect some decolorization.

The use of double silicates of lime and alumina, either the minerals or artificial compounds, for removing potassium and sodium from the juice is theoretically interesting but not yet tried out in practice. By filtering thin or thick juices, sirup or molasses over such coarsely powdered silicates, these liquors give up their alkalies forming the corresponding lime salts. There is actually no purification of the juice, but only a transformation of its alkaline salts into lime salts, which do not hinder the crys-

tallization of the sugar so much, and are not so melassagenic as the alkaline salts. On the other hand, the lime salts alter the characteristics of juices and sirups, making them more viscous and harder to work in the vacuum pan. Hence, it is very questionable whether this process can be considered an important improvement. There seems no profit in using these silicates, although they can be renewed easily by treatment with a calcium chloride solution, nor is much gained by recovering the potassium chloride.

Electrolysis, particularly in the case of the crude juice, with lead or zinc electrodes and simultaneous use of dialysis, exerts a favorable action; but such a process is far too expensive and the sugar-losses are altogether too great, so that this electrodialysis cannot find permanent, practical application.

Formerly acids, such as oxalic, phosphoric, or even hydrochloric acid, were sometimes introduced into the diffusers in order to reduce the solubility of those substances which cause the difficult filtration of the scums from the carbonatated juice. The success obtained from use of these chemicals is doubtful; probably their chief effect lies in the injury to the walls of the diffusers. The use of such antiseptic agents as phenol or formaldehyde to prevent evolution of gas in the diffusers, or in fact any fermentation of the juice, is altogether ineffectual, for it is possible to add such substances only in very small amounts, or else they become too expensive, and moreover, they impart to the sugar an unpleasant taste and odor.

CHAPTER XII.

EVAPORATION.

By means of evaporating apparatus the thin juice is concentrated from a density of 12–13° Brix (6.8–7.40 Bé) to a sirup of about 60° Brix (33° Bé.), about 80% of water being removed, reckoned on the weight of the juice. Factories having evaporators whose heating-surface is small or inefficient do well to get a concentration to 50° (27.7° Bé.), but obviously they waste steam and coal. A proper evaporating-plant should be designed to give under unfavorable circumstances a sirup of at least 55-60 Brix. Concentrations as high as 65–70° (35.6–38.1° Bé.) are not advisable, because such heavy sirup makes the vacuum-pan work harder, and it also may happen that by cooling in the pipes crystals are deposited and stoppages may occur.

The average **quantity of thin liquor** which is obtained ordinarily, reckoned for a factory using dry defecation and two per cent. of lime per 100 kilos (220 lbs.) of beets, is about as follows:

Obtained from the diffusion: about 105 liters (27.7 gals.)	110 kg. (242 lbs.)
Sweet water from filter-presses, 125% of 8% scums	10 kg. (22 lbs.)
Various concentrates	2 kg. (4.4 lbs.)
Total thin juice	122 kg. (268.4 lbs.)

In factories using defecation with milk of lime, the lime used up is somewhat more and the amount of sweet water somewhat greater. Moreover, there is usually not enough of the latter to slake the

lime, so that the yield under these conditions must be reckoned at least 125 kg. of juice per 100 kg. of beets.

Diffusion-juice which has a sugar-content of from 12 to 13 per cent. consequently gives a thin liquor of from 10.5 to 11.5 per cent. of sucrose. In the average factory working up 550 tons of beets a day there are about 687.5 tons of thin liquor; in the larger ones working up 1,100 to 2,200 tons per diem there will be from 1,375 to 2,750 avoirdupois tons of thin liquor to concentrate.

For evaporating such enormous amounts of water there is in existence apparatus of many different makes and principles of working. The heating-surface of the ordinary types consists of tubes held in position by tube-plates. In vertical apparatus the juice is evaporated in the tubes; in the horizontal types it passes over the outside of the tubes. In the former the length of the tubes is usually 1.25–1.50 meters (4–5 ft.), in the horizontal evaporators 3–4 m. (10–13 ft.), their diameters varying between 20 and 50 mm. ($\frac{3}{4}$–2 inches). The general principles on which such apparatus works, leaving out of consideration special types for special purposes, are practically identical. Every evaporator should be equipped with an accurate thermometer and mercury vacuum-gauge, as well as properly placed sight-glasses, as well as those for illumination, so that the interior can be easily inspected at all times.

In **single-effect apparatus** one kilo of steam will evaporate an equivalent amount of water at the usual temperature obtained, that is to say, a kilo. The heat of the steam coming from the evaporator can be further utilized by using it over again for evaporating or heating in a separate vessel. Our consideration of the work of the single-effect apparatus, which we will now take up, will not have to do with steam-ecomony only so far as to ascertain under what conditions the greatest possible amount of water can be evaporated based on this unit for the heating-surface, and under what conditions it is at its maximum efficiency without being subject to special disadvantages.

The amount of heat which passes through the heating walls in

a unit of time is directly proportional to the temperature fall, i.e., to the difference in temperature of the heating vapors and the boiling liquid, and also to the conductivity of the metal of the heating wall. It is inversely proportional to the thickness of the heating wall and to the magnitude of a certain resistance which opposes the conductivity.

This **resistance** comes from stationary liquid films on each side of the heating surface which are caused by the adhesion of the water and liquors to the heat wall. Hence the heat does not pass directly from the steam into the metal, but first into the water flowing along the heating surface and from this into the stationary water film clinging to the metal and thence into the metal. On the liquor side, it is the same, only reversed, from the metal, the heat passes through the stationary fluid film before entering the moving liquor.

Since the conductivity of water and water solutions is 100 times smaller than that of iron and 120 times smaller than for brass, it is obvious that stationary films of exceeding thinness will impede the heat transference greatly.

Any condition influencing the thickness of this motionless film affects the heat transference. This thickness depends on the speed of movement of the water and liquors and on their viscosity, the latter being inversely proportional to the temperature of the liquid and directly proportional to its concentration. The speed of movement depends on the construction of the evaporating apparatus, and for boiling liquors is dependent besides on the quantity of steam bubbles which are given off.

Hence, the **heat-transference** from steam to the boiling liquid is in proportion to:

1. The speed of the movement of the liquor over the heating-surface;

2. Inversely as the height of liquor, or its pressure, on the heating-surface;

3. The speed with which the steam circulates over the heating-surface;

4. The speed and thoroughness with which the condensed water is taken away from the heating-surface;

5. The completeness of the vacuum in the evaporating-chamber.

6. The conductivity of the heating-surface, that is, its freedom from scale and foreign substance;

7. Inversely as the viscosity of the liquor;

8. The temperature of the liquor, which depends upon the pressure under which it boils.

9. The magnitude of the temperature-drop between the steam and the boiling liquor.

These conditions for good heat-transference should be attained in the simplest possible manner, so that in actual practice the construction is without complication, all parts are capable of easy inspection, and the apparatus easy to run. There should also be security against juice loss: and finally the evaporation should not be too expensive.

In short, simplicity in construction and working are the chief requisites in all sugar-house evaporators. Since evaporators work night and day, only a few hours on Sunday being available for cleaning and repairs, all parts should be made with a view of avoiding all chance of interruptions to the work of the factory, especially those which might require more than ordinary care and attention, since the running of evaporators must usually be left to unskilled labor.

This requirement of simplicity is usually met in a very satisfactory way in the **horizontal and vertical apparatus** found in most factories. With other types, some of which are recommended on quite sound theoretical grounds, such as the **film apparatus,** interruptions and irregularity in working are continual, so that properly such have not found much footing in the industry. In place of a vertical-tube system, some evaporators have been built with inclined tubes and are recommended both for evaporation and crystallization. For certain purposes they may have some advantages, but it has not appeared that they are

any more efficient than a properly constructed vertical apparatus.

It must always be kept in mind that the efficiency of an evaporating apparatus is of course the leading consideration, and it certainly makes no difference whether you pay the same price per square foot of heating-surface in one case as for two square feet in an apparatus of different make of only half the efficiency. Indeed the efficiency of an evaporating apparatus, speaking generally, is dependent not on the special heat economy of the whole system, but entirely on the proper arrangement and combination of the individual parts.

The efficiency of a single-effect apparatus, therefore, does not depend primarily on any special design, although this is always an important consideration. With whatever apparatus is at hand, the object should always be to work it to its highest efficiency. With such an end in view, excellent results can be obtained with very simple means and costly enlargements of the evaporating-plant be avoided, if the fundamental requirements for the case at hand are thoroughly understood. A brief description of the means of increasing the efficiency of the ordinary vertical and horizontal evaporators seems therefore necessary.

The most important influences on the efficiency of an evaporator are the **juice-level** and the **juice-circulation.** Formerly it was thought necesary to keep the juice-level in vertical apparatus at least high enough to fully cover the upper tube-plate, so that the liquor would be at least as deep as the tubes were long, that is, $1\frac{1}{4}$–$1\frac{1}{2}$ meters (4–5 ft.). It was the same in the ordinary horizontal evaporators. However, the deeper the juice-layer which rests on the heating-surface, the higher proportionally the pressure on that part of the heating-surface and consequently the boiling-point. The fact that actual experiments with thermometers show exactly the same temperatures at the top and bottom of the heating system is no argument against this statement, since the movement of the liquor in the apparatus is so swift that juice overheated at any part of the heating-surface directly against it immediately moves on,

and, after giving up its excess of heat, mixes in with the common circulation, so that the temperature, measured by introducing a thermometer, will be equal at all points. Nevertheless it is true that liquor next to the heating-surface under a head of juice, as well as the heating-surface itself, must have a higher temperature, if bubbles are given off and this liquor is not circulating with the rest. Certainly this is so when the bubbles are escaping, or otherwise no steam could be formed. The difference in temperature between the steam used for heating and that of the liquor which is in actual contact with the heating-surface is less, therefore, the greater the head of liquor. Since the rate of evaporation is approximately proportional to the temperature-fall, it follows that the efficiency of an evaporating apparatus is diminished by keeping the juice at a high level. On this account the heating-tubes in vertical apparatus have been made shorter, but with the disadvantage that the heating-surface was diminished, since for other reasons the diameter of an evaporator should not exceed 3 meters (10 feet).

Such shortening of the heating-tubes is not only unnecessary, but indeed detrimental to the evaporating efficiency if the apparatus is worked at a low juice-level. The juice will be projected out of the tubes by the escaping steam-bubbles, and will rise in foam so that the tubes throughout their entire length will be covered with liquor, the circulation over the heating-surface will be rapid, and in consequence of the foam only a slight pressure will be exerted by the bubbles. The longer the heating-surfaces are, up to a certain limit, the more rapid the juice-circulation without marked increase of pressure in the lower part and the greater the efficiency of the heating-surface.

How low the juice-level should be carried, as shown by a juice-gauge working according to the principle of communicating tubes, depends on many conditions, especially on the viscosity of the liquor and the volume of the steam-bubbles formed from a specified quantity of water. In the last effect containing concentrated liquor, therefore, the level can be maintained lower than with thin juice. Experience teaches the proper height, but care should be taken to have the juice always foaming or spurting out of all heating-tubes.

In the horizontal apparatus, also, the juice-level should be as low as possible, although these will not work as satisfactorily as the vertical. Nevertheless it is possible with horizontal makes to get a very large heating-surface with small height of steam-chest if the *trunk shape* ("wagon-top") design is used. This form is therefore the best of all.

In order to increase and facilitate the juice-circulation of vertical evaporators, circulation-tubes of large diameter are placed in the middle or distributed through the heating-surface, these serving to return the juice coming out of the top of the tubes down to the bottom of the apparatus. Often the juice flows back at the outer edge of the tube system, this being so suspended as to form a ring-space between the walls of the evaporator and the tube section. In the horizontal evaporators the single tubes or tube sections should be sufficiently far apart to allow the juice to find its way to the bottom readily.

Another way to increase the speed-circulation of juice consists in hanging wooden or enamelled iron rods in the heating-tubes so that their circular section is contracted to a ring. The trouble with using wooden rods is that they become disintegrated through action of the heat and the alkalies in the juice, while after boiling out the apparatus with acid they color the juice dark. Iron rods in proportion to their usefulness are too expensive.

The speed of the juice-circulation can also be increased by using tubes of smaller diameter, because the capacity of a tube decreases much faster than its heating-surface. Usually narrower tubes are used for the first effect than for the last, so as to have the diameter of the heating-tubes bear a certain relation to the volume of the escaping steam.

A contrivance for improving the juice-circulation in the first effect of a multiple-effect apparatus is called the "*circulator*" and consists of a small vertical evaporating apparatus connected with the regular thin-juice effect above and below. The circulator is heated with direct steam, which throws up the juice in bubbles and forces it over into the tube system of the large apparatus, while the juice in the bottom of the large effect passes into the small apparatus.

The use of this circulator is very doubtful, because the circulation induced by it in the large apparatus is one which already exists there, but in exactly the reverse direction. If the circulator is advantageous, it is because it utilizes the high temperature of direct steam, better than by mixing live steam with exhaust whose temperature and pressure make it useless for expansion. Hence in the circulator the temperature fall is very much greater than in the first effect, with which it is connected and its capacity per unit of heating surface likewise greater.

The heat-transference depends also upon **the speed with which the steam passes over the heating-surface** and upon the readiness with which **condensed water is taken away from the heating-surface.** In vertical apparatus the speed of the steam in the heating chambers is not great, whereas the condensed water flows away from the vertical tubes quickly and completely. In horizontal apparatus a great speed can be obtained by a suitable arrangement of the heating-tubes in sections, especially if the tubes have a small diameter, only 20 mm. ($\frac{3}{4}$ inch) or less. The speed is only very great, however, in the region adjacent to the steam-entrance; as the steam goes toward the condensation discharge-pipe its velocity lessens till it finally becomes practically zero. The condensed water flows but slowly in the tubes of the horizontal apparatus; in fact the lower parts will never be quite free from water unless it collects in places where the flow of the steam-current is swift, so that the water is carried along with it. Vertical apparatus should be improved so as to increase the steam-flow, while in horizontal apparatus the aim should be to carry away the water.

All steam, direct as well as exhaust, carries a small amount of uncondensed gases, especially air, small quantities of carbon dioxide, and ammonia. Usually these condensed gases are referred to as "ammonia-vapor," although the bulk of the ammonia is absorbed by the condenser water. If these gases are not taken away, they collect in the heating-chambers and take up a constantly increasing space, which is consequently lost for condensation and likewise for heat-transference; hence the importance of **completely and continually removing these gases** is obvious, and the more

so when it is remembered that the ammonia always present in combination with the oxygen of the air corrodes brass and copper tubes badly if allowed to remain long in one place. Attempts have been made to remove the ammonia collecting in the exhaust-steam piping, by means of sulphurous acid, sulphuric acid, potash alum, or other absorbing agent, with the hope of getting back the increased expense by the value of the ammonia recovered; but these contrivances have not proved economical. The amount of ammonia in the exhaust-steam has been greatly overestimated.

In the evaporation of the juice of 100 kg. (220 lbs.) of beets from 20 to 30 grams (about an ounce) of ammonia has been obtained under favorable conditions, so that in a factory of average capacity there would be recovered daily only from 100 to 200 kg. (220–440 lbs.) of ammonia gas. This small amount does not pay for the costly and unreliable apparatus which would have to be built into each effect of the evaporator. Moreover, such apparatus would only mitigate the corrosion, since gases other than ammonia still remain in the steam to be sucked off. Such a gas is carbon dioxide, which originates in the juice and which escapes in large quantities, especially from over-carbonatated liquors. Frequently this gas forms ammonium carbonate with the ammonia in such quantities as sometimes to stop up small pipes.

Naturally a large escape of gas does not occur when the steam passes into the heating-chambers, where there is always a strong current but there are spaces where this current is quite slow, and it is there that the gas collects. Experience has shown that in vertical apparatus only the upper ends of the brass tubes are corroded, from which it has been correctly inferred that the gas collects only in the top of the heating-chamber. Vent-pipes are therefore placed in the top tube-plate, arranged in different places according to the number and position of the steam-inlets. If there is only one steam-inlet, the pipe is located where it can exhaust most efficiently, that is, where the uncondensable gases contain least steam, at a point farthest from the outer edge and the middle circulation-pipe. If there are two steam-entrances on

opposite sides, then the place to vent is half-way between them. Should experience show that there was corrosion at other points, vents must be put in at such places also, for these corroded spots are unmistakable signs of a collection of gas. In placing vent-pipes in the tube-plate care must be taken not to let them project through the tube-plate, but to cut them off flush with the under side, otherwise there will be a collecting-space which cannot be exhausted of gas. In order to prevent corrosion of the upper part of the tubes entirely it is also suggested that they be coated with a durable varnish or specially protected in some similar way.

In the horizontal evaporators the steam-entrance is always at one end; in consequence the uncondensable gases will be forced to the exit ends of the tubes or into the tube-chest, together with the condensed water. The vents should therefore be at the top of the exit-chamber. If the tubes are not perfectly horizontal but bent, the gas will collect in these bent tubes and corrode them in a short time.

As already mentioned, it is impossible to remove only gas; a comparatively large quantity of steam escapes at the same time. Just how far gas-venting should be carried can be determined only by actual experience. A little too much is better than not enough, for the steam-loss is not so serious as a bad corrosion of the tubes and consequent wearing out of apparatus. Most care should be given to the venting of the heating-chamber of the first effect, because here the steam is at its greatest efficiency; the vapors in the later effects, which have been used over several times, have less pressure, so that the gases can be drawn off freely, opening the cocks fairly wide. As a limit it may be stated that the vent-valves or cocks of the first effect should not have an opening of more than 5 or 10 mm. ($\frac{1}{5}$–$\frac{2}{5}$ inch). If they happen to be larger, their openings should be reduced, or a diaphragm with a hole of the appropriate size screwed into the pipe. On the other hand, the valves of the last effects can have a diameter of 25–50 mm. (1–2 in.) and should be at least half open. In order to keep the heat-loss within reasonable limits, the steam which is taken off and which contains less than 1% of uncondensable gas is not

led to the condenser but to the evaporating-chamber of the same effect, so that the steam is used in the next effect.

It should be seen that a rapid and complete exhaustion in the evaporator can be obtained at the time it is started, when the heating-chambers are full of air.

Before the heat of the steam can act on the liquor it must first pass the **walls of the heating-surface.** The material used for the tubes is usually brass, iron, or steel; copper is little used for evaporators, except in the coils of vacuum-pans. The conductivity of metals varies considerably, although this difference is of little consequence if the heating-surfaces of the tubes are clean. More depends on the thickness of the walls, especially as the walls of an iron tube, which is a poorer conductor, must be thicker than those of a brass tube. A very important point is the **condition of the heating-surface,** not only on the juice side, but the steam side also. The most important consideration which makes brass tubes better than those of iron is that the iron after a short time becomes covered with a thin coating of rust which cannot be removed and conducts heat badly. Iron tubes with especially thin walls have been used in many factories, but these thin-walled tubes are not to be recommended, because they are attacked when the apparatus is boiled out with muriatic acid and soon must be renewed because of leaks. On the juice side the sole problem with tubes of all kinds is that of **scale-deposit.**

There are indeed few cases of thin juices which do not deposit scale however well filtered and defecated. The salts which are the chief scale formers, namely, those of lime with carbonic, sulphuric, sulphurous, oxalic, and some organic acids, are but partly soluble in the thin juice. Being more soluble in thin juice they precipitate, not only from the evaporation but also on account of their slight solubility in the thickened juice, and form a firm coating on the heating-surfaces. If the thickness of the scale keeps within moderate limits, the evaporating efficiency of the apparatus does not suffer appreciably, but in the course of time the amount of deposit becomes so great that measures must be taken to remove it.

The amount of deposit varies greatly in the different vessels

of a multiple-effect apparatus. If the juice is well defecated, carbonatated, filtered, and boiled up, very little deposit is found in the first effect, but in the later effects there will be more or less according to the content of difficultly soluble lime salts. If the final carbonatation is incomplete or not carried out hot enough, or the filtration carelessly done, a thick scale will appear in the first effect. This deposit consists mostly of little slime-particles which get into the apparatus, the deposits in the later effects being caused by the precipitation of the lime salts dissolved in the thin liquors through their concentration. Hence boiling up the juice before evaporating will not prevent the formation of these deposits in the later effects. Boiling up of the juice before and after final carbonatation is so effective that there is little use for a special blow-up plant for thin liquor which has been properly carbonatated and filtered, as experience has often shown in those places where work goes on without Sunday intermissions. What seems more advisable in such cases is introducing a filter-plant for the juice passing from one effect to the next, in some cases using pumps if the difference in pressure is too small.

Removal of scale by mechanical means, such as brushes, scrapers, or cutters, is only possible in vertical evaporators during crop time: not in the horizontal ones, because their tubes have to be removed for this purpose. Indeed mechanical cleaning of vertical apparatus is difficult, slow, and laborious. Hence chemical cleaning is practiced everywhere, either boiling out with soda and then with muriatic acid or with acid alone, which with rare exceptions, providing the boiling is thoroughly done every Sunday, keeps up the efficiency of the apparatus throughout the crop.

If the scale-deposit is practically all carbonate of lime, boiling with muriatic acid is sufficient. Often, however, there are other lime salts present which form deposits not readily soluble in muriatic acid, more particularly lime salts of sulphurous, sulphuric, or oxalic acid; likewise lime soaps which are formed from fats introduced to prevent foaming. Other occasional constituents of scale are silicic acid, alumina, and iron oxide, which come from the lime; likewise undecomposed fats, which do harm so far as they

prevent disintegration of the scale by the boiling liquors and therefore impede the action of the muriatic acid. In all such cases it is advisable to boil with dilute soda solution first, so as to change lime salts into carbonate and disintegrate the scale by dissolving the free fats. The scale so treated dissolves easily in muriatic acid. If it is desirable to dispense with a double boiling out, a charge of sodium bisulphite (acid sulphite) is excellent, as this changes the lime carbonates and organic salts into sulphites which expand and so crack and break up the hard scale that it is readily attacked by the muriatic acid. Rarely scale resists this treatment, unless it contains a large amount of silica and alumina, when mechanical means must be resorted to.

Muriatic acid used for cleaning evaporators must not be too concentrated, as it should under no circumstances dissolve any appreciable amount of iron which would weaken the apparatus. The scale makes sufficient protection to the walls of the apparatus if dilute acid is used. The amount of hydrochloric acid in the acid water should never be more than 1% for the last effect where the scale is most, and not more than $\frac{1}{4}$–$\frac{1}{2}$ per cent. in the preceding effects. To prevent the walls from being attacked by the muriatic acid as it enters, as might easily happen if it is too concentrated, it is a good idea to draw it into the apparatus while the water is boiling under vacuum by means of a pipe extending into the middle, as when the water is boiling the mixture will be immediate The boiling should not be at too high a temperature and should last 1–2 hours. If the work is done in that way, the apparatus is brought to its original efficiency, it is in nowise injured, and should be good for twenty years' work, or more.

While boiling out with acid, acidity tests of the condensation-water should be taken. If it reacts acid, it should not be used for boiler-feed, or it should be first neutralized with soda.

The soda solution used for boiling out should contain $\frac{1}{2}$ to $1\frac{1}{2}$ per cent. of anhydrous sodium carbonate. Boiling out with this solution should be as long as possible, and the highest possible temperature should be maintained in all effects. The vacuum is therefore lowered by opening the air-valves, or most of the water is turned

off the condenser. Violent boiling is not necessary here, as is the case when muriatic acid is used. It is sufficient if the liquor is merely moving.

After boiling out with muriatic acid, the evaporator is immediately emptied of acid water and very carefully washed out with pure water, the best way being to fill up over the tubes. All water connections of the evaporator should come from a common pipe closed by one main valve. This valve is securely locked when the apparatus is running, so that no water can mix with juice through any misuse of it. No inspection of the apparatus should be made after it has been boiled out till sufficient air has been sucked in by the vacuum-pump to insure against any possible danger from detonating gas being inside.

If the full efficiency is not restored after boiling out, it is a sign that the solutions were too weak or that the boiling out was not long enough. This will have to be rectified the following Sunday. It is not, however, necessary that the tubes be completely clean and free from scale after boiling out, as long as the evaporation is as good as ever, and the scale-deposit thinner, and especially if it has become porous. It is obvious that all apparatus must be fitted with suitable valves for introducing chemicals and boiling them up quickly. Everything should be arranged as conveniently as possible for utilizing to best advantage the short resting-time which Sunday affords.

The viscosity of the juice exerts another most important influence on the heat-transference in evaporators. Since the juice has a purity of 90 or more, there are but little non-sugars in proportion to the sucrose, and their influence is so small that the variable constitution of the juice need not be taken into consideration. Juices of the same concentration have practically the same viscosity, but this viscosity increases enormously in proportion to the concentration of the juice, that is with its sugar-content. Hence thickened juices are much more viscous than thin ones and make the capacity of the thick-juice effects notably less than that of the thin-juice effects.

Moreover, the last effects work under more unfavorable conditions in one other point, namely, that, owing to the higher vacuum,

they have a lower boiling-temperature than the first effect. The **heat-transference is less at a lower temperature** than at a higher, all other conditions being equal, and this heat-coefficient falls rapidly at temperatures below the boiling-point, while at 100° or over the change is not so great. It would be more advantageous, therefore, from this point of view, to have all the effects evaporate at a temperature of about 100° or over. The highest pressure of engine exhaust-steam is, however, under usual conditions $\frac{3}{4}$–1 atmosphere (12–15 lbs.), hence its temperature is as high as 115°–120° (239°–248° F.), which gives too small a range for the entire temperature-drop necessary for a multiple effect. Aside from this, the thicker sirups must be evaporated at the lowest possible temperature to avoid decomposition.

As a preventive of the injurious influence of the unavoidably low boiling-temperature in the last effects, resort is made to an **increase in temperature-fall** in the effects boiling under a vacuum. By increasing this fall not only is the amount of heat transferred corresponding to this fall greater, but the heat-transference coefficient rises proportionally. This coefficient, that is the amount of heat transferred to one square meter of heating-surface in one hour for every degree centigrade, is about 10 for a temperature-fall from 75° to 65°, but for a fall from 85° to 65° it is about 15. In practice, therefore, use must be made of this fact.

There should be no **mechanical sugar-loss** in a properly constructed evaporating apparatus. The only cause for such loss is in **leaks** in tubes or tube-plates. While running no loss of juice can commonly occur here, as the pressure of the steam in the heating-chamber is obviously always greater than in the evaporating section, including the pressure of the juice-column. Indeed steam and condensed water can enter the juice at any leaky spot, but the juice can never enter the steam-space. When work is interrupted the conditions become quite different, and thin juice loss is the unavoidable consequence of such leaks. Therefore great care should be taken to keep the tubes in good condition and the tube-plates tight. Before the campaign, the apparatus when

ready to start should be tested by water-pressure, and especially the multiple effects, using the water-tank pressure which is always more than 1 atmosphere (15 lbs.) and putting on the juice-boiler a pressure higher than the highest steam-pressure used. In vertical apparatus the water-pressure should be on the steam-chamber, in the horizontal evaporators on the juice side, so that every tube will be tested for leaks.

The second cause of sugar-loss is **entrainment of juice-spray** in the exit-vapors. In this way much loss can take place if unfavorable conditions exist. Entrainment of juice is more likely the greater the evolution of steam from the juice, the more energetic the escape of bubbles from the surface of the liquor, the higher the viscosity, and the more rapid the current of vapors passing out of the apparatus.

In the first effect, danger of entrainment is very small because when under pressure or light vacuum the escaping steam has little volume, while the juice is thin and mobile and the vapor-current slow. In the later effects, on the contrary, where the steam has nearly six times the volume it has under atmospheric pressure, the viscous sirup is more or less atomized by the exploding bubbles. This escaping spray goes through the tubes where the speed of the vapor-current is 100 meters (328 ft.), or more, a second and is entrained into the condenser and lost in the hot-well.

Juice-catchers made in various ways are placed in the vapor-pipe lines for trapping this juice-spray, the common principle on which they work being to retain the minute drops of liquor either on the surfaces of sieves or vertical partitions, or to allow them to fall into an enlarged chamber in the pipe. The value of these juice-traps is often doubtful. They can do harm if the juice which is caught does not flow back at once into the evaporator. This juice, which is much diluted by the condensed water, cools and becomes a breeding place for micro-organisms which quickly propagate in great quantities. If this badly infected juice flows into a thick juice effect, the bacteria will continue to propagate if the vacuum is high, since the temperature will be low. The temperature of the thick juice effects never is high enough to

trouble bacteria. Hence the thickened juice is infected with living germs which readily pass over into the product later in process unless the juice is subsequently filtered and heated sufficiently long at 100° C. The best juice-trap is a lofty evaporating-chamber. Two opposing forces are continuously at work upon the spray thrown off from the surface of the boiling juice. The initial velocity with which this spray is hurled upward, either directly or obliquely, is augmented by the upward current of the vapor, but it is also continually diminished by the influence of gravity. In the broad space of the evaporating-chamber the speed of the steam-current is only about 4–5 meters (13–16.5 ft.) a second, about equal to the velocity of a moderate breeze. At such speed there is little tendency for the thin liquor to spurt up, but the restraining force of gravity is the same whether the drops of liquor are large or small. Experience has shown that the vapor-space of the evaporator should extend from 3 to 5 meters (10 to 16.5 ft.) above the juice-level in order to have the smallest particles of spray lose their upward velocity. If this be done, there need be little fear of sugar-loss even in the thick-sirup effects.

There is a common belief that it is not the drops which are entrained, but bubbles consisting of thin films filled with vapor. Naturally bubbles of this nature, owing to their slight density and relatively large volume, would readily be entrained, but for this bubble hypothesis there is no good scientific reason, and scarcely any actual evidence. It is certainly a fact that no juice, or, if any, a quite negligible quantity, is entrained if the vapor-spaces are sufficiently high, as can be easily proved by testing the water in the hot-well for sugar. A good and convenient control apparatus for determining whether sugar is entrained consists of a trap on the bottom of any horizontal section of the vapor-pipe. A small portion of any sirup entrained will deposit with the water condensed on the walls of the pipe and will flow into the trap. Naturally this will only show that sugar-loss sometimes occurs, but if the water in the trap shows no sugar, or only a trace, it can be assumed with confidence that any sugar-loss must be exceedingly small.

Multiple-effect Evaporating Apparatus.—In constructing single effects the principal considerations are reliability of working and speedy and efficient evaporation, but the peculiar arrangement of the evaporating system of the multiple effect has the additional object of more complete economy of the heat of exhaust and direct steam by using it over a number of times for evaporating, heating, and boiling.

The number of effects united in one system shows the number of times the heat of the steam is utilized, although occasionally two or more evaporating-vessels will be heated with steam at the same pressure. In the latter case such vessels can be considered as one member of the multiple-effect apparatus. In such arrangements it is better not to introduce the vapor and the juice directly into each vessel, but to unite the vessels in such a way that the juice from the preceding effect enters one of them and passes out through a large overflow pipe into the bottom of the next, the vapors going in the reverse direction. By this arrangement greater efficiency and easier control are effected, since, by regulating the juice-level in the first vessel, the juice-level of the other is adjusted.

There are certain *limits* to the use of steam in multiple effects. The total temperature-fall, that is the difference between the temperature of the steam used to heat the first effect (exhaust-steam) and the temperature of the boiling sirup in the last effect, is at most 50° (122° F.), since the exhaust-steam when engines are working economically (and if they do not, the work suffers) is at never more than $\frac{3}{4}$ of an atmosphere (11 lbs.), while the vacuum is rarely higher than 60 cm. (23.6 inches). This total temperature-drop cannot, however, be divided into any desired number of smaller temperature changes, but rather a lower limit of fall is set for each effect below which a good evaporation cannot be obtained even by increasing the heating-surface. Practical experience teaches that the temperature-fall in the first effect, whose contents are boiling at 100° or over, should not be under 4°–5°, in the middle effects 7°–10°, and in the last effect not less than 15°. Hence it follows that division of the total temperature-fall into

more than six parts is not practically feasible, and hence sextuple effects represent the highest limit of multiplication used in sugar-manufacture. But since there are also great difficulties arising in the sextuple use of exhaust-steam, even quintuple effects have not become common in factories, quadruples being mostly used, although many triples are employed, either with or without juice-heaters.

If the amount of steam which an evaporator will use for boiling and heating is estimated, it should be on the assumption that all the vapor from one effect of an evaporating system passes into the next effect and is condensed, all its available heat being transferred through the heating-walls into the juice and being utilized in evaporation.

One kilogram of steam on condensing gives out different amounts of heat according to the temperature of the condensed water. If the cooling which the condensed water undergoes when flowing away from the heating-tubes is taken into consideration, and this differs according to the construction of the heating-tubes, but is never very great, it will be found that this water has a temperature which will cause it to boil under the vacuum of the heating-chamber. Therefore, the higher the pressure of the heating vapors, the greater the amount of heat that the condensation-water will retain. Hence in a single effect not 1 kg. of water is evaporated by 1 kg. of steam, but somewhat less, and likewise a multiple-effect evaporator does not evaporate 2, 3, 4, or more kg. out of the juice, but always less, in proportion to the excess of heat of the condensed water over that of the boiling juice. This quantity of heat is, however, so small as to be negligible in practical work.

If there is approximately the same quantity of water to be evaporated out of the juice in each effect, **all the heating-surfaces should not be equally large,** since the magnitude of the heat-transference in different effects is very different. As has been already shown above, the conditions for heat-transference are much more unfavorable in the last effect than in the first. In the last effects the sirup has more viscosity, the boiling-temperature is lower, and the deposit of scale greater. In order to attain the greatest possible efficiency of the whole evaporating system, these unalterable,

unfavorable conditions existing in the last effect must be counterbalanced by making others more favorable but without affecting the efficiency of the first effect.

The **means at hand for increasing the heat-transference of the last effects** are to increase the temperature-fall and to keep the boiling-temperature not too low by too high a vacuum. If the vacuum rises much above 60 cm. (24 inches), it is true that the temperature-fall increases more in proportion to every centimeter rise in the vacuum, but the heat-transference coefficient decreases in much greater proportion as the boiling-temperature sinks. Hence it appears useless to keep the vacuum higher than 60 cm., and indeed such high vacuums are difficult to reach unless a large amount of cold water and a perfectly working vacuum-pump are available. Taking all circumstances of actual practice into consideration, it is best to work at a vacuum of about 60 cm.

Another means of increasing the efficiency of the last effects and likewise of the whole multiple effect is to increase the temperature-fall. Since, as has just been shown, the boiling-temperature cannot be advantageously lowered more than that corresponding to 60 cm. vacuum, the temperature of the heating-vapors must be raised. It follows that these later effects should be made smaller, especially as the total temperature-drop of the whole system is fixed once for all. The apportioning of this temperature-drop must be such as to have in the first effect the smallest practicable difference in temperature between the steam and the boiling juice, while the remaining temperature-drop should be greater proportionately in each succeeding effect. It follows further that the first effect must have the greatest heating-surface, as there is less temperature-drop here for evaporating the necessary amount of water from the juice, while the last effects require proportionately less heating-surface.

Besides, the first effects should be made still larger, so as **to give steam for the heating and boiling of the juice and sirup.** It will depend mainly on the extent and the heat-transference efficiency of the heating-surfaces in the cookers and heaters, the initial temperature of the juice, and the temperature required as to whether the heating-vapors be taken from the first or second effect

or whether one shall furnish heat for boiling and the other for heating.

If the boiling-point in the first effect is too low for heating and boiling, because the later effects are too large and the vapor pressure in all the effects are too low, the pressure can be raised in the first effect or in both first and second effects as high as is compatible with the pressure of the exit-vapors by inserting throttle-valves in the vapor-pipes. Such arrangements should only be installed under the express condition that they are recommended by experts, and should be so constructed that they could not be completely closed.

Cold raw juice especially can be heated by the exhaust-vapors of the last effect, because these have a temperature of 60°–70° (140°–158° F.), while the juice is at only 25°–35° (77°–95° F.). This method of heating is very desirable because it is entirely without fuel-cost, since the heat would otherwise be lost. Such a heater has no influence on the size of the evaporator nor on cost of manufacture, because it is placed in the exit-pipe to the dry condenser.

All the other liquors require for their heating steam of 90°–100° (194°–212° F.) or over. This must consequently be taken from the first two effects of a quadruple-effect evaporator or from the first effect of a triple, or from the juice-cooker, if there is one, and first effect.

The so-called **juice-cooker** or **preheater** is an additional vertical evaporating-vessel of the multiple system which is heated with high-pressure or reduced live steam.

The installation of such a juice-cooker is especially desirable where exhaust-steam is not available for the evaporation and live steam is consequently used, and also where steam of the highest available pressure must be used for cooking and heating, such as cannot be had from the quadruple effect.

In the juice-cooker the steam for boiling may be as high as $\frac{3}{4}$ of an atmosphere (11 lbs.) or even 1 atmosphere (15 lbs.), the boiling temperature being raised to 115°–120° (239°–248° F.) without fear of decomposing sucrose or that the juice will be made darker, provided it is sufficiently alkaline. By use of such high pres-

sures the heating-surfaces of cooking and heating apparatus can be made proportionately small and the steampipes of smaller diameter. It is on this account that these juice-cookers have become popular in spite of many practical objections to them. In most factories they use one juice-heater, but some use two or even three the first heated by live steam, the second heated from the exhaust-steam from the first. This arrangement is particularly recommended in cases where, owing to the centralization of the motive power, little exhaust-steam is available. The live steam is thus utilized twice, and the waste vapors can then be used in conjunction with the evaporator vapors for heating and boiling.

There are certain *difficulties* connected with the working of the juice-heaters, partly on account of their being outside the real evaporating system, which can, however, be overcome. In the first place it is not advisable to draw or pump all of the juice through the juice-heater, because it is unnecessary that all of the juice should be brought to such high temperature. When the juice is drawn over into the first effect of the multiple evaporator from the juice-cooker it gives off its excess heat in the form of steam, so that considerably less engine exhaust-steam will be condensed and proportionally more live steam will be used. It is advisable, therefore, to draw in to the juice-cooker only enough juice to keep its density not higher than 15°–20° Brix. (8.5°–11.3° Bé.), while the excess of juice is drawn directly into the first effect, where it mixes with that from the juice-heater. Where several juice-heaters are used this is not done. As it is absolutely necessary to keep the juice moving through, owing to the high temperature, all the juice goes through the first heater and then through the others.

Another difficulty encountered in running the juice-heater according to the usual method is due to the fact that more work is required of it at one time than at another. For instance, when a vacuum-pan is just started, very much steam must be used to thicken the sirup, although during graining but

little is required. It may happen at times that, owing to a momentary stoppage in the juice-pipe, all the exhaust cannot be used in the first effect, while the juice-cooker at the same moment needs a large amount of steam. The result is that a large quantity of steam is taken from the boilers, while the exhaust blows off over the roof. To avoid this trouble, there should be an exhaust-steam line connected with the steam line of the last juice-cooker the valve of which should as a rule be kept open during the working of the heater.

There is then a common pipe system for the exhaust and the steam used in the cooker, from which lead all the connections to the heating and boiling apparatus. The last juice-cooker, therefore, controls the pressure of the exhaust, and the regulation of the steam used in heating simply depends on the pressure desired. In this way the steam will be used in the most efficient and reliable manner, and the work will be remarkably uniform. It will never happen that the juice foams in the cooker, because the evolution and escape of steam will be much more regular, so that sudden upheavals caused by rapid falling of the pressure and consequent foaming will never occur.

If the juice-cooker is thus introduced into the common steam system, the contrivances so often recommended for controlling the inflow of live steam which are regulated by the pressure in the boiling-chamber will be not only unnecessary but rather superfluous, as violent and rapid pressure-changes will not take place, and the man in charge has merely to look at the steam-gauge.

Whether a juice-cooker is used or not, the evaporating-plant must be designed so as to give *under all conditions sirup of the required density*, even if irregularities do occur in the work. Irregularities of this sort for which, it is needless to say, often all sorts of ideas about evaporating apparatus are responsible, can never be prevented in actual practice; they are partly dependent on special conditions in the sugar-house, as, for instance, on extreme variations in the amount of exhaust-steam used in making massecuite from sirup in the vacuum-pan work. Another thing, the juice-supply is never uniform; at times, owing to stoppages of the beet-slicers or uneven pressure, the diffusion-juice comes irregularly, at other times the rate of carbonatation varies, again the filter-

presses run unevenly; in short, there are frequent cases when the juice is in excess, and which the tanks could not take care of if the evaporating capacity were figured for an average juice-supply.

The capacity of an evaporating-plant should be calculated not only with allowance for steam taken for heating and boiling, but for evaporating the desired amount of juice when only a part of this steam is withdrawn. Besides, there should be an excess calculated over the necessary heating-surface for the average juice-yield: (1) of about 10% allowed in all effects for occasions when work is forced, and (2) for loss in heat-transference of the heating-surfaces from scale. Since this scale is formed in appreciable quantities only in the last effects, the increase in the heating-surface should be put there. While an increase in heating-surface of all effects of the evaporating system helps take care of a greater juice-supply, withdrawing more of the exit-vapors for use in boiling and heating from any one effect obviously influences only that effect and the one ahead of it, if there be such. Usually this irregular withdrawal of steam affects only the first effect and the juice-cooker. It is not, however, necessary to reckon the area of the heating-surface necessary for the maximum possible quantity of steam, it being sufficient, if a possible increase in the temperature of the vapors is taken into consideration, to calculate the heating-surface for the average quantity of steam to be withdrawn. As the efficiency of an evaporator within narrow limits is practically proportional to the temperature-drop, and since this temperature-drop never exceeds 6°–8° C. (11°–14° F.), an increase in the temperature of the steam used in evaporating of 2°–3° C. (3.5°–5.5° F.) (corresponding to an increase in the exhaust-steam pressure of 0.2 atmosphere or 3 lbs.) will be enough to raise the efficiency of an effect from 25 to 33 per cent. This increase is quite sufficient to provide for even maximum variations in the use of steam in the boiling and heating plants.

A multiple effect by no means works in a fixed mechanical routine. Any slight changes which are continually occurring in the conditions of evaporating or in other existing circumstances affect its efficiency to a very great extent.

The temperature-drop in the different effects shows most variation, and on this depends the heat-transmission coefficient and consequently the efficiency of the evaporator. All calculations of heating-surface are based on a certain theoretical standard of evaporation, which is no less valuable even if later conditions of actual practice alter it. The great efficiency of the multiple effect is not equal to what can be calculated theoretically, because all conditions of practice cannot be predicted.

Experience has taught us to arrange evaporators in a line consisting of elements exactly alike, a convenient number of which are united in one body. Each element is trunk-shaped and has its own heating-chamber filled with vertical tubes. This heating-chamber is connected by a branch with the general steam system, and the tail-pipes lead by one or several branches from each special heating-chamber to the trap system. The juice-circulation in such evaporators must be especially good, since each separate heating system (effect) has to be separated from the others by suitable space. In this way apparatus already installed can be easily enlarged without great expense and structural alterations, if such increase becomes necessary. Likewise changes in the heating-surface of different elements of the evaporator can be easily made if these appear advantageous.

The basis for the **calculation of amount of heating-surface** is the **heat-transference coefficient.** For the ordinary vertical or horizontal trunk-shaped evaporators the following figures can be taken as averages for practical use.

The coefficients in a quadruple effect are: in I (including the juice-cooker) 40–50, in II 30–40, in III 20–30, in IV 10–15.

In a triple effect: in I 40–50, in II 30–40, in III 12–15.

A necessary requirement in the application of these figures is that the apparatus is properly handled and put together. If the proper amount of steam is calculated, for juice-evaporation and for withdrawal in heating and boiling, there will be all the necessary data for figuring out the heating-surfaces. (See Appendix II.) It is especially important to figure the temperature of the exit-vapors low enough and make the temperature-drop in the first

effect small. The heating-surface of this effect should be especially large, for this extensive heating-surface is of the greatest value, as it insures the efficiency of the whole multiple effect under all possible conditions.

The **value of an evaporating-plant** whose capacity has been calculated in the manner described depends on how the steam of the factory is used for heating purposes. Theory and practice have shown that the economy is greater the more the steam *is taken from the vapors of the evaporators for boiling and heating* and the use of live steam avoided as much as possible. Hence a better utilization can be made of the vapors of a quadruple effect for heating and boiling than of those of a quintuple or sextuple effect, where such use is not advantageous. A triple effect can do even better, provided fuel is not too expensive. The **juice extraction** does not have such a great influence on the work of sugar-houses with well-designed evaporators as it used to in more primitive plants. As shown in the calculation of Appendix II, the total steam consumption of a factory per 100 kg. (220 lbs.) of beets, when the extraction was 115 kg. (223 lbs.) of diffusion juice was 61.7 kg. (135.7 lbs.) being only 3 kg. (6.6 lbs.) less, or 58.7 kg. (12.91 lbs.), when the extraction was 105 kg. (231 lbs.). The entire **amount of steam used** in the factory for evaporating, when the evaporators are properly calculated and of convenient simplicity for best practical work, is, exclusive of cooling-losses, about 60 per cent of the weight of the beets. No house ought to use more than 70 per cent. of steam, and all of this steam should be used as exhaust or live steam in the juice-cooker and the first effect, provided no live steam is necessary for the overflow-heaters of the diffusion plant as when they are heated by direct injection. As shown by tables in Appendix III, if the number of effects of an evaporating-plant is increased, which of course means better utilization of the exhaust-steam, or improvements are made in the application of the heat of the exit-vapors in boiling and heating, obviously the steam-consumption can be still further cut down. The more the steam is economized in evaporation the more evident become the losses by cooling and other wastes, and are forced on our attention.

In every case where improvements are made, careful calculations will show whether the greater coal-economy resulting has paid for the increased cost of installation and alterations.

A theoretically interesting method of multiple steam-utilization, not yet introduced into actual practice, which is capable of reducing the steam-consumption still more, consists in compressing the exit-vapors of the first and second effects with a pump to the original exhaust-steam pressure and hence restoring its efficiency. Evidently such procedure is only practicable where pumps can be driven by water-power. Moreover, the trouble would be that the compressed vapors would be strongly superheated. **Highly superheated steam** is, however, entirely useless for evaporating apparatus because, unless it is cooled to the saturation-temperature, it acts like a gas and gives up its heat very slowly to the heating-surfaces. Even water-injection does not increase the heat-transference sufficiently. Again, the compressor-pump must be well oiled, and in consequence the compressed steam contains oil which sticks on the heating-surfaces and lessens the heat-transference. This trouble can be overcome by use of high-pressure blowers instead of pumps.

The advantages of this system can be attained without the attendant drawbacks mentioned if **steam-injection apparatus** is used. By use of this apparatus exhaust-steam of low pressure can be raised by live steam to a pressure about $\frac{1}{2}$ an atmosphere (8 lbs.) higher without the mixed steam losing heat or undergoing perceptible superheating.

The amount of exhaust-steam which can be brought to a higher pressure by this means depends on the boiler-pressure and the pressure-increase desired. To compress 1 kg. of exhaust-steam about $\frac{1}{2}$ an atmosphere (8 lbs.) 2 kg. of live steam at 6 atmospheres (90 lbs.) pressure are necessary. To the extent that live steam at high pressure must be used in the evaporating-plant, this steam-jet apparatus can be recommended as a very inexpensive contrivance for better economizing steam. It is important that the jet apparatus always works with full boiler-pressure. Since the amount of live steam necessary is very variable, it is a necessary

requirement to install not one jet apparatus only, that works at its highest efficiency at the maximum boiler-pressure, but several smaller ones which collectively have the same capacity, so that as many can be put into action as the amount of live steam available permits.

The steam-economy which can be attained by steam-jet apparatus on the first effect sucking vapors from the second is theoretically as much, approximately, as obtained by installing a juice-cooker.

At the beginning of work when the evaporating apparatus is not running, and during Sunday stops or interruptions of the factory, it is necessary to use live steam. The valves in evaporators, heaters, and pans should be always carefully watched to prevent them being opened through carelessness: they should be locked or the wheels taken off. The best way is to have a large stop-valve on the main exhaust-line leading to the heaters and vacuum apparatus and through which the necessary live steam is admitted. One valve can be looked after much better than several.

As already stated, the greatest **sugar-loss from decomposition of sucrose** does not occur in evaporators, provided the highest boiling temperature does not exceed 115°–120° C. (239°–248° F.) and provided the juice is sufficiently alkaline; yet it cannot be denied that a small amount of sucrose, not exceeding a few hundredths of a per cent., is destroyed. This loss increases not only with the temperature, but with the length of time that the juice is exposed to such temperature. For instance, of 100 parts of sucrose in the juice at 100° (212° F.) 0.114 part of sugar is destroyed in an hour; at 110° (230° F.) 0.163 part; and at 115° (239° F.) 0.175 part. The average time that juice is in an evaporator is only half an hour if the temperature is 115° (239° F.). In apparatus evaporating at an average temperature of 100° (212° F.) and consequently slower, the juice is in an hour and the sugar-decomposition is consequently greater.

The juice is likewise delayed in the evaporator if its juice-content is too great or if it is evaporated with too little temperature drop. This juice content is too great if the juice-level is too high during

evaporating or if, in horizontal evaporators, there is too much useless space below the tubes in vertical apparatus or between tubes in the horizontal type. Evaporating should be done under a *low* juice-head and the apparatus made as large as consideration of juice-circulation demands. The bad habit must be avoided of filling up the evaporator with juice when there is a large supply of thin liquor on hand or the sirup is coming off too heavy, and thereby at once lowering the efficiency of apparatus of even the largest capacity. There will be too much juice in the evaporator also, aside from troubles in the factory, if the heating-surface is too great for the amount of thin liquor.

The boiling-point of no evaporator should rise above 120° (248° F.), at least not for any length of time, as the sucrose decomposition increases very fast with every degree rise above this temperature. In an hour, 100 parts of sugar lose by decomposition 0.28 parts at 120° (248° F.) 0.53 parts at 125° (257° F.) and 2.05 parts at 130° (266° F.).

If, for any reason, thin liquors must be evaporated which are neutral or weakly acid (a manner of working which, taking everything into consideration, seems utterly wrong), the boiling-point ought never to rise above 100° (212° F.), and even this is risky. Under such circumstances evaporating cannot be done with economy. Considerable sugar-loss, accompanied with a large drop in alkalinity, occasionally occurs from the introduction of juice infected with bacteria coming from badly designed juice catchers (see above). Likewise evaporators which are so constructed as to have a space under the tubes where the juice can cool will breed active colonies of bacteria, especially leuconostoc. No such losses will occur if proper construction is used for preventing entrainment. If there are juice catchers, it is advisable to send any juice they trap back to the defecation instead of letting it go into the thickened juice.

Control of evaporating apparatus has these objects: (1) Regulation of the steam-supply according to the thin liquor on hand; (2) Preventing the steam-pressure in the first effect and the juice-heater from rising above the upper limits prescribed; (3) Keeping

the vacuum in the last effect uniformly at the proper point; (4) Seeing that the juice is at the lowest possible level in all effects; (5) Taking care that the sirup is discharged at a uniform rate and density. If these details are rigorously seen to, all others will take care of themselves.

Since the engine-exhaust is usually inadequate for the evaporators, it is seldom necessary to regulate the exhaust-valve. When there is lack of juice, however, this valve must be closed and the steam allowed to blow off through an escape-valve. It is never advisable in such cases to take in water instead of juice and evaporate it so as to stop the steam blowing off, since this always damages the juice.

The pressure in the steam-chamber of the first effect ought never to be higher than what is best for the engines, since excessive back-pressure of the exhaust impedes them and lowers their economy. The introduction of live steam or of the exhaust from the juice-cooker into the main exhaust system must consequently be regulated by the pressure in the steam-chamber of the first effect.

The vacuum in the last effect must be kept uniform, since any drop makes a corresponding increase in pressure in the preceding effects. Especially important is keeping **the concentration of sirup uniform,** since any increase in the density of the sirup, especially above 60° Brix (33° Bé.), makes a marked increase in the boiling-point and viscosity and consequent perceptible increase in the pressure of the preceding effects.

Raising the boiling-point diminishes the true temperature-fall, while increase in viscosity lowers the heat-transference coefficient, which for sirup of 60° Brix (33° Bé.) is only about $\frac{2}{3}$ that of water, sinking to about $\frac{1}{3}$ for sirup of 70° Brix (38° Bé.). The statement that the smaller specific heat of the sirup has influence on this coefficient is erroneous. A uniform concentration of sirup is also most advantageous for working it up in the processes which follow. Hence frequent spindle-readings should be made, or, what is better, use automatic apparatus for showing the density constantly. A specially constructed hydrometer cylinder with overflow-pipe

attached to the discharge-pipe of the sirup-pump is simple and convenient, as a spindle can be kept floating in the sirup.

Montejus are seldom used for taking away sirup. Pumps are much more convenient in every way, particularly because the sirup can be drawn off continuously and its density kept uniform much more easily. These pumps overcome the vacuum of the apparatus better if they are set as low as possible, so that the juice-head in part balances the effect of the vacuum.

The **flow of juice** from one effect to another should be continuous and not in gushes. Skillful workmen soon learn to set the valves so that they seldom have to be altered, especially when the juice is coming to the evaporator regularly. The liquor-entrance pipes should never discharge over the heating-tubes, but always in the bottom and through a perforated pipe which lies under the tubes. Since the juice goes from an effect under higher pressure into one at lower pressure, it is superheated as it enters the latter and immediately gives off a large amount of steam which atomizes the juice and, when the opening of the pipe is above the tubes, causes a loss by entrainment. If the juice enters under the tubes, these steam-bubbles which are formed are very useful in improving its circulation.

The juice-gauge must be properly set if it is to indicate properly; that is, the lower end must be connected below the tubes and the upper end above them. Juice-gauges which are entirely above the tubes are of no use. Large sight-glasses and also illuminating-glasses, for easily seeing the interior, should be placed in all apparatus.

If all these directions are followed, every apparatus will show certain characteristics which can be considered normal and constant for every effect, providing the steam-pressures and the vacuum on the condensers remain constant, and which change in a perfectly regular way if either the steam or the vacuum changes.

Variations from these regular values are due to **interruptions in the running** of the apparatus and are always followed by diminished efficiency. If these irregularities appear about the end of the week or when the vacuum in the last effect remains constant, but the pressure of the preceding effects goes up, it is a sign of *scale-deposit*

on the tubes. Directions as to duration of boiling out and the liquors to use for removing scale have already been given.

Irregularities in the pressure relations of the effects also come from incomplete removal of condensation-waters ("sweet-waters") from the steam-chambers, the area of the heating-surface being diminished. In order to detect presence of water in the heating-chambers, they should be provided with guage-glasses.

The **removal of condensed water** from heating-chambers where the steam is at more than atmospheric pressure is made by float-traps, which should be inspected frequently to make certain that they remove the water completely but allow no steam to pass. The water condensed in the last effect is either pumped away or carried by a pipe into a tank placed low, so that its water-level is below that corresponding to the highest vacuum in the heating-chamber, say 6–7 meters (19–22 ft.) below it. Sometimes condensed water from the other effects is led into this tank or well, being pumped thence to where it is needed, but this mixture of hot and cooler water is not advisable; it is better to keep that which is over 100° (212° F.) separate and use it for boiler-feed, employing the cooler for diffusion, sweetening off filter-presses, slaking lime, etc.

In some factories attempts have been made to utilize the heat of this hot condensed water for evaporation by passing it over from one heating-chamber into the next following, so that the water under the diminished pressure of this second chamber gives off its superheat in the form of steam. Finally all of the water comes to the heating-chamber of the last effect and is discharged at the temperature of this chamber. If this method is used, care must be taken to have the tail-pipes specially large in order to prevent waterlogging. Any special advantage in this is not clear, as this heat, although utilized in the evaporator, is lost by the boilers.

The pressure-relations will also change if the juice *foams badly*, whatever the cause. Foaming within certain limits is very advantageous for evaporation at a low juice-level, as has already been explained. If, however, the foaming is too strong, the heating-surfaces are no longer sufficiently wetted. Every dry spot is useless,

and consequently bad foaming always raises the pressure in the heating-chamber. A fat whose viscosity is as small as possible has to be used to stop this foaming, and as little as practicable, since lime soaps and undecomposed fats make trouble both in the evaporation and in the sirup-filtration. The fat can be introduced through the butter-cup in effects boiling below atmospheric pressure; in those boiling higher an oil-pump must be used.

A low vacuum in the last effect and consequent high pressures in the preceding effects, a trouble which is frequently experienced at the beginning of the campaign, is caused by *leaks* in the joints of the apparatus and vapor-pipes lowering the vacuum on account of the air entering the condenser and overloading the air-pump. Those leaks which cannot be detected by the noise of the air rushing in can be found by running over the joints with a lamp-flame, and must be stopped up with cement.

No good reason has been found for making a change in the simple methods of running evaporating apparatus. Proposals for altering them have never been popular in actual practice, and it is useless to detail propositions which are frequently made on paper but have never been worked out by actual experience.

CHAPTER XIII.

THE CONDENSATION OF THE EVAPORATION-VAPORS.

WHEREAS in the double-effect evaporator that was used years ago there was a large amount of juice-vapors to be condensed, owing to the slight utilization of these vapors for heating and evaporation, to-day, with the more economical arrangement of the evaporation-vessels, there is but a relatively small amount of vapor which reaches the condensers.

Everywhere that there is a heating or boiling apparatus there is a corresponding condensation of steam. Consequently all of the heating and boiling apparatus may be regarded as condensers, and indeed as surface condensers. However, when the term *condenser* is ordinarily used in connection with the sugar industry, reference is made to the injection-condensers, whose sole purpose is to condense steam or vapor.

In the case of an extensive heating of the juice and its evaporation in a quadruple effect, there will be from 100 kilograms of water, corresponding to about 100 kilograms of beets, only about 10 kilograms of vapor given off by the last effect to pass over into the condenser; although even a part of this vapor may be utilized for heating the raw juice and condensed in the preheaters. The remaining 90 kilograms of water are condensed upon the heating-surfaces of the evaporating, heating and boiling apparatus, and recovered in the form of pure condenser-water containing a little ammonia.

Besides the vapors from the last-juice effect of the evaporator, those from the boiling apparatus must also be condensed. According to the density of the sirup there will be between 10 and

15 kilograms of water evaporated from each 100 kilograms of beets, or in other words there will be at least as much vapor to condense coming from the vacuum-pans as from the last effect of the multiple evaporator, but with the difference that there will be a practically uniform evolution of vapor from the latter during the whole of the twenty-four hours in a day, whereas the amount of vapor from the vacuum-pans varies from time to time very considerably. Hence the condensing apparatus for the latter should be figured not for the average amount of vapor given off, but from the maximum amount evolved at any time.

Every **condensation plant** consists of an injection-condenser and an air-pump.

The **air-pumps** are either *wet* or *dry*—they either pump only the uncondensed gases from out of the condenser, or they pump out as well the hot water which has effected the condensation. The *wet* air-pumps possess the disadvantage that scale is almost always deposited in them from the hot water, and furthermore, when they are used, the advantage gained from using a counter-current condenser is to some extent neutralized, because the cooled gases, as they come in contact with the hot water, are warmed again, occupy a greater volume and consequently diminish the efficiency of the pumps. Therefore *dry* air-pumps are to be preferred in the sugar-factory, preferably with high vertical condensers from which the water (hot-well water, as it is called) flows off through a *leg-pipe* or barometrical tube.

Counter-current condensers are most used, and in these the vapors enter at the bottom; as they pass upward they come in contact with a current of water flowing in the opposite direction. The disadvantage that was formerly found in these condensers, which prevented their adoption and gave rise to preference for the less efficient parallel condensers, was that the air-pumps were *drowned* by their damming up, resulting in irregular working of the system. This evil has been overcome by making the condensers very tall and of large diameter, and by adding spray-plates, sufficiently apart

from one another, particularly at the lower portions of the condenser where the vapors enter. It has been found advantageous not to introduce the vapors at the very bottom of the condenser, but high enough above the bottom so that there is space left for the vapors to move downward for a little way with the current of descending water. In this way all damming up of the condensers, which is otherwise sometimes met with even in condensers of normal size, is prevented. The inner arrangement of the condenser may be quite different in the various types. In one form the water flows along a winding path, in another it falls cataract fashion over plates set diagonally against one another, while in still another type the water falls like rain in fine drops. For sugar-factory purposes all of these different forms work satisfactorily, if by the injection of a sufficient amount of cold water the desirable vacuum of about 60 centimeters can be readily produced, and, as has been shown in the preceding chapter, it is of no particular advantage to use a pump constructed for a higher vacuum. For the vacuum-pans also, it is neither necessary nor desirable to have a greater vacuum than 60 cm.

A condenser is acting satisfactorily when it produces a vacuum of about 60 centimeters and the hot-well water flows away with a temperature not more than 10 degrees lower than that of the vapors coming from the multiple effect, and when the gases passing into the pump have been cooled to a temperature which is approximately that of the water entering the condenser. In order to be able to control the work of the condensers, it is advisable to put thermometers both in the leg-pipe and in the suction-pipe of the air-pump. When these thermometers show abnormal temperatures immediate information is given of poor working of the condensers, and particularly as to whether too much or too little water is injected into the condenser, or whether the pump is working properly.

The length of the leg-pipe should be at least 10 meters (33 ft.) from the lower edge of the condenser to the upper level of the hot-well. Even if this height is not absolutely essential with

ordinary vacuum corresponding to 60 cm. of mercury column, it is always advisable to make it as much as this because it is impossible entirely to avoid deviations in the height of the water-column in the leg-pipe, and these deviations sometimes amount to as much as one meter (3 ft.) or more. The leg-pipe should, furthermore, be of large diameter, especially when the water contains considerable sand and small stones, which would clog up the pipe during the campaign if it were too narrow. During the campaign it is impossible to clean this pipe without stopping all of the work, as it is very important that the condenser should be in constant working order.

The amount of injection-water required depends altogether upon the temperature of the hot-well as compared with that of the hot vapors and of the injection-water. Under ordinary conditions when the difference between the temperatures of the vapors which are at 62° to 65° C. (144°–149° F.) and the hot-well is about 10° C., and the injection-water is from 10° to 15° C. (50°–60° F.), it will be necessary to inject about 15 kilograms of water for one kilogram of vapor; or reckoned another way, it will require about 150 kilos of water for the vapors from the first concentration of the juice, and from 150 to 225 kilos for the vapors from the final boiling down of the juice, for every 100 kilos of beets. If the vacuum be increased, the difference in temperature between the vapors and the injected water is lessened and consequently more of the latter must be used.

The amount of injected water used corresponds to the calculated amount only when the vapors come off regularly, as is the case with vapors from the first concentration of the juice but not with the vapors from the vacuum-pans. The amount of water required is particularly variable when each boiling apparatus is provided with its own special condenser and a special air-pump; its control is much more difficult, and the plant is expensive.

It is, therefore, generally customary to make use either of **one common condenser** or at least a **central air-pump.** It is unquestionably true, with regard to the amount of

water consumed and the simplicity of the working, that the centralizing of the condenser-plant is the most satisfactory. On the other hand, it is claimed that the large vapor-valves which must be inserted in the pipes before each single apparatus, in order to be able to cut out any one of them from the system, are hard to keep tight, and further that the boiling down of the sirup to make it crystallize is more difficult where the vacuum is kept uniform than when the pan man can regulate the vacuum at will by turning the water on or off at each separate condenser. This last objection is, however, a weak one, because it is only a matter of practice for the pan man to be able to conduct the boiling down equally good at a constant vacuum. In fact it is really simpler to boil at uniform vacuum. When it is desired to boil a particularly uniform product, say coarse granulated sugar, it is perhaps easier for most sugar-boilers to make the necessary changes in the vacuum with the separate condensers than by regulating the vapor-valve. These latter valves are manufactured so well at the present time, and they are made so tight by means of vulcanized fibre, that the other reasons against the use of a centralized condenser system are no longer tenable. Gate-valves have also proved satisfactory. As a rule, the vapor-pipes, and in consequence the valves, of vacuum-pans are made too large. This not only increases the expense, but also the difficulty in keeping the valves tight.

When a central pump works different condensers it is necessary to insert a valve in the suction-pipe of each separate condenser, for cutting it out. This arrangement is very convenient in many ways, although considerably more water will be required than is the case with a single condenser, because there is no equalization in the rates at which the vapors come from the different concentrators as when a single condenser is used. It is necessary to give more attention to separate condensers, particularly if economy in the use of the water is desired.

In factories where there is no scarcity of fresh water the hot-well water serves partly as pressure-water in the diffusers, but is

chiefly used for washing beets and in the hydraulic carrier. Where there is scarcity of water, the hot well-water is cooled by running it over steps or into cooling and spraying appliances, so that it reaches a temperature, dependent partly upon the outdoor temperature and the amount of wind, low enough so that it can be used over again in the factory and also for condensing purposes.

CHAPTER XIV.

CARBONATATION AND FILTRATION OF THE CONCENTRATED JUICE OR SIRUP.

SIRUP from the evaporators has a yellow or brown color, and is turbid from a fine precipitate which separates out during evaporation. **Its alkalinity,** as has already been stated, depends on the alkalinity of the thin liquors and the composition of the juice. The decrease in alkalinity during evaporation will be in proportion to the amount of ammonia, amido or albuminous substances, invert, sugar, and lime salts held in the thin liquor. If such decrease did not take place, a sirup of 60° Brix (33° Bé.) should have five times the alkalinity of a thin liquor of 12° Brix (6.8° Bé.), while as a rule the alkalinity of sirup is only from three to four times greater, so that the balance either is distilled as ammonia or neutralized by the alkalies combining in reactions with the decomposition-products of the nitrogenous substances, invert-sugar, and lime salts.

Moreover, the color of sirup is darker than corresponds to the concentration. If sirup is diluted with water to the original concentration of the thin liquor, it will be darker than thin liquor.

The normal alkalinity of the uncarbonatated sirup is from 0.07 to 0.15 per cent. Since a sirup as strongly alkaline as this is not suitable to work up in the vacuum-pan, it is carbonatated either with carbonic or sulphurous acid or with both at the same time. In many factories the alkalinity is lowered nearly to a neutral reaction, while others consider that an alkalinity of 0.03–0.04 is proper. Here also it is better to fix the alkalinity according to the behavior of the sirup in the later stages of the process. If the alkalinity decreases much in the vacuum-pan, the alkalinity of

the sirup should be kept high enough so that the massecuite as well as the first sugars and molasses ("green sirup") will show a distinct red color with phenolphthaleïn. If, on the contrary, the sirup contains much free alkali and no lime salts, it can be carbonatated almost to neutrality, since any decrease in alkalinity in such cases is little to be feared. The objection attributed to high alkalinity that it makes the sirup work up harder in the vacuum-pan and that it increases the ash in the sugar is unwarranted. The only thing that makes the pan work harder is when the alkalinity is due to caustic lime, which means that sucrates will be present. This cannot be with an alkalinity of 0.03–0.05, as this is almost invariably from combinations of carbonic acid with the alkaline earths, ammonia, or organic bases. Moreover, high ash-content is not a result of alkalinity. Under the most favorable conditions, when carbonatation with carbonic or sulphurous acid is thorough, the carbonates and sulphites would react with any caustic lime and be precipitated in considerable quantity as lime carbonate or sulphite. There would be at most, therefore, 0.03–0.05 part of lime in 100 parts of sirup, which corresponds to 1.5–2.0 parts total ash, scarcely perceptible in the sugar. Since the reactions of carbonic and sulphurous acids with lime salts are never complete, especially if filtration immediately follows carbonatation, a small amount of lime will always be precipitated by further carbonatation, and consequently, taking into consideration the influence this has on the sugar-yield, it is hardly wise to make a carbonatation as far as the neutral point. However, this is of little consequence in its bearing on the ash-content of the sirup in comparison with the much more important point of keeping the proper temperature during carbonatation, and above all things a good filtration.

The sirup which is pumped out of the evaporator is only at the temperature corresponding to the boiling-point of the last effect, that is 70° C. (158° F.). Before carbonatation it should be brought almost to boiling, which is best done by using special exhaust-steam heaters. Direct-steam injectors are of no use here, as they would dilute the sirup too much.

The **carbonatation of the sirup** is best done *continuously* in

one tank, pumping the sirup through it and at the same time introducing the carbonic or sulphurous acid according to the alkalinity required, the sirup running to the filters at the same rate that it is pumped in. In such cases it is advisable to add kieselguhr (fossil meal) about 1 kilogram per cubic meter of juice (8.34 lbs. per 1000 gals.) The carbonatation tank should have a stirrer to mix in the kieselguhr evenly. Kieselguhr can always be added to advantage to the thickened juice of the first runnings at the beginning of the campaign and at the start of each week's work, as the juice at such times is full of dirt and rust from the apparatus, likewise when much oil has to be used in the evaporators owing to foaming.

Ordinarily lime is not added to the sirup, it being quite superfluous if the thin liquor and corresponding uncarbonatated sirup is sufficiently alkaline. Such sirups, having an alkalinity of 0.07–0.15 in carbonatating at the boiling temperature, give sufficient granular precipitate to enclose the scummy material so that usually they filter very well. If, however, the sirup is very slightly alkaline, owing to carbonatating too far, there is little or no precipitate and it filters badly.

Sometimes **addition of a little milk of lime** helps, but it seems that sirup coming from the evaporator, which already has a high alkalinity, always filters better. If lime is added to the sirup, it will affect it some time later if the temperature is high, and continuous carbonatation is not applicable in such cases or it must be done differently.

In the clarifying and later working up of sirup it is of no consequence whether carbonic or sulphurous acid is used in carbonatation. Carbonatation with sulphurous acid has the advantage that it gives lighter sirups and sugars, and owing to the small quantity of sulphites retained they keep better. Indeed, if sulphurous acid is to be used for treating beet-juices, it should be applied only to sirups, and here its use is strongly to be recommended.

The same apparatus serves for **sirup-filtration** as for thin liquors, but in general a somewhat higher pressure is preferable for sirups, for which **filter-presses** of special design, with wooden chambers

and the sand filters previously described, are used. The sirup running from the filters in the beginning always comes cloudy, and is returned to the thin-liquor carbonatation-tanks till it runs clear enough for the sirup-tanks. The scums which collect on the cloths cannot be sweetened off, so presses with sweetening-off passages are as little in use as in thin-liquor filtration. Since, however, these scums are rich in sugar, it has been recommended to return them to the carbonatation-tanks. When the filter-cloths are removed they likewise are full of sugary sirup. It is doubtful whether it is advisable to soak these cloths to recover this sugar, as the sirup, from remaining an unavoidably long time, is always much deteriorated. As a rule the sugar-loss in scums and cloths is so small that it is not worth taking into consideration.

In most cases sirups filter fairly well, but there will be those which filter badly if at all, especially those heavier than 60° Brix (33° Bé.). In such cases it is advisable **to carbonatate and filter the so-called intermediate sirup** ("mittelsaft"), that is the sirup as it comes out of the effect of the evaporator preceding the last. This sirup, which is about 30° Brix (17° Bé.), is pumped to the carbonatation-tank and treated there in the manner prescribed for sirup and drawn into the last effect, where it is concentrated to the usual density. This will again cloud up a little, but the bulk of the scum is now filtered out of it and very efficiently, so that a second sirup-filtration can be dispensed with. The filtration of the intermediate sirup is especially advisable when the sirup deposits much scale in the multiple effect, since the scale is formed principally from this scum, which precipitates out from the thin liquor while concentrating, and sticks to the tubes.

Sometimes this intermediate sirup is clarified in a closed filter (using gravel or bone-black or by a closed filter-press) so introduced between the last effect and the one next to the last that the sirup must pass through it. Leaving out of consideration that this arrangement is quite inconvenient and that the pressure-difference is often insufficient for filtering, obviously carbonatation is wanting before filtering. However, in many factories the juice is carbonatated in the evaporator itself, by passing sulphurous acid into the

juice while boiling inside, but this kind of carbonatation is by no means easy to control and is not therefore to be recommended.

There are no sure methods of determining whether a sirup has the right composition to work up easily. A juice or sirup of high purity will surely work up well, but with beets of poor quality where the sirup only has a purity of 90 or under, neither chemical analysis nor color has any criterion on this point. Often there is a belief that the amount of lime present, that is the **content of lime salts,** is a measure of how the juice will work up, but the truth is, everything depends on the nature of these lime salts. Sometimes an excessive quantity of these salts is to a certain extent a sign that juice of bad beets must be improved as much as possible by energetic treatment with lime. Color is no guide to the quality of a sirup.

It certainly would be quite wrong to conclude that a light-colored sirup, especially one which had been bleached with all sorts of chemicals and made weakly acid with sulphurous acid, was better than a darker sirup, and that better products could be made from the former.

If the thin liquor has been properly treated according to the directions given, the best possible sirup under the circumstances will be obtained, but it is surely not practicable to get a good clarification of sirup if the thin liquor has been carelessly treated, as mistakes made in the thin-liquor treatment cannot be remedied later in the sirup.

CHAPTER XV.

SUGAR-BOILING.

AFTER the sirup has been filtered, it is evaporated to grain in a **vacuum-pan.** This apparatus should serve both for evaporation of the sirup and for crystallization of the sugar, and consequently both of these requirements must be satisfied, but the chief essential is that there should be a proper crystallization of the sugar. In general, this vacuum apparatus is similar in shape and arrangement to that previously described, except that certain changes are made necessary in order to concentrate liquids which, thick and viscous at the start, become at the last a pasty mass. Usually vacuum-pans are vertical with conical bottoms. The heating-surfaces are coils placed one over the other or intertwined, heating-tubes of Lyra type arranged horizontally. Sometimes short and wide tubes or vertical tubes are built into heating-chambers arranged for introduction of steam and carrying off condensed water. The horizontal vacuum-pans always are of a trunk shape, arranged like evaporating-pans, and have a single bottom suitably inclined towards the discharge-gate. All heating-surfaces are placed as low as possible, so that they are covered with sirup from the beginning.

Iron is the metal very frequently used for making these heating-tubes, it having the advantage over brass and copper that it is less attacked by ammonia-vapors, while the disadvantage that it is a poorer conductor of heat of is less consequence here because the amount of heat to be transmitted to the juice is of itself very inconsiderable. In the vacuum-pan, ammonia-vapors act more injuriously upon the heating-tubes than in the evaporating-pans,

because with the former, toward the end of the operation, there is less movement of hot vapors, and hence these ammonia-vapors move slower and may collect in certain places.

The discharge-gate of vacuum-pans is usually a cone. When massecuites are boiled down with considerable sirup, so that a relatively thin liquor remains, the discharge-opening is closed with a valve. The double bottom, which was formerly quite universally used, is now usually dispensed with, although it does accomplish a certain desirable effect, because with such an arrangement bubbles of steam are formed down in the lower layers, and this is favorable to the movement of the massecuite and facilitates the boiling and crystallization. As a method of heating, however, the double bottom is not very efficient, the heating coefficient being very low.

The **equipment of vacuum-pans** must otherwise be such that the pan man can easily control his boiling and readily detect anything wrong and remedy the evil. The sample or proof-stick should be correctly placed, where there is sufficient movement of the massecuite to insure taking a proof which shall represent the average content. There should be an abundance of sight-glasses in the sides, so arranged that the interior of the pan can be readily seen. The thermometer and its stem must penetrate sufficiently deep. A mercury gauge should be provided to show the amount of vacuum. The charging valves must be large and conveniently arranged. The charging pipe, whether inside or outside, must lead to the bottom of the apparatus and end in a suitable distributing arrangement. For heating, steam of high or low tension, as required, must be used and the corresponding connections to the main valves should be easily made. The sugar-boiler must be able to read the steam-pressure both as it leaves and enters the heating system by a gauge. Of course the heating system must be equipped with pipes for conducting away condensation-water, and suitably arranged for leading off ammonia-vapors. Special valves should be provided for drawing in cold or hot water. It is very practical to introduce a perforated coil, or a similar distributing arrangement, in order to be able to introduce live steam directly into the massecuite

and set it in motion. After the strike is down this steam may be carried through special pipes and used for evaporating.

The size of vacuum-pans is very variable. A large apparatus naturally demands less attention than several small pans having the same capacity. On the other hand, taking into consideration the work of the factory as a whole, and in particular that of the evaporation apparatus, as already mentioned, it is less advantageous to have but one large vacuum-pan; for when this is started it requires more steam from the evaporators than the latter can give. As the process proceeds, less sirup will be drawn in and less steam will be required, so that finally none at all is used, as the sirup gets thick. Consequently it is necessary that every factory should have at least two boiling-pans of suitable size, in order to take care of the sirup systematically and make the use of steam uniform.

With regard to the **size of the heating-surface** in vacuum-pans there is no definite rule to give; it is not possible to calculate it as in the case of the multiple effect, since the conditions affecting the transference of heat are so varied during the boiling process, and at different times quite different amounts of water are to be evaporated. In this apparatus evaporation is only a means to the chief end, namely, the crystallization of the sugar. Since heating-surface in excess cannot do any harm if placed at the bottom of the apparatus and under no conditions does it influence the circulation of the massecuite, it is well to make this large. It is then always possible, and particularly at the start, to conduct the evaporation quickly and make use of low-pressure steam for evaporating. The amount of heat conveyed to the boiling mass, or in other words the evaporation, in this case does not depend upon the size of the heating-surfaces, but upon the amount and tension of the steam admitted into the heating-space. Since with large heating-surfaces only a part of this steam is really active, it is advisable, when possible, to construct the heating system with several compartments each of which is provided with independent pipes for introduction of steam and conducting away condensation-water, these compartments being heated as they are

needed. In all cases it should be possible to regulate the evaporation by means of the valves, so that the proper conditions for favorable crystallization of the sugar shall prevail. Vacuum-pans with a capacity of 20,000 to 50,000 kilograms (20 to 50 long tons), which is the common size now chosen, have a heating-surface of from 80 to 150 square meters (860–1600 sq. ft.).

The question as to best construction of the boiling apparatus and of heating-surfaces is one that is hard to answer. A skillful sugar-boiler will be able to produce good sugar in any apparatus in which the heating-surfaces are active and do not hinder the circulation. The fact that a sugar-boiler gets bad results in a new apparatus, while he has been doing well with an old one to which he has become accustomed, is not conclusive proof that the new vacuum-pan is bad. Boiling in grain is an art which is usually learned entirely experimentally and must be learned anew for a differently constructed apparatus and for every masscuite of different consistency.

+ The **art of boiling to grain** consists in forming the necessary number of crystals in the thickened sirup and then in further boiling, allowing only these particular crystals to grow without forming a perceptible amount of new ones. The operator accomplishes this by hazarding a conclusion as to the concentration of the sirup by the outward appearance of the sample which he takes from the apparatus. It would be quite useless to attempt to describe here just how the boiler arrives at the proper conclusion. It is only possible to acquire this skill by practical experience, and every individual has his own peculiar method.

The important point with regard to the art of sugar-boiling in grain and which serves for the judgment of the correctness or inaccuracy of individual methods is a **knowledge of the actual processes which are taking place during the operation.**

For crystals to form in a sugar-solution and for these crystals to grow, it is necessary that the solution become "supersaturated." A solution containing sugar is "**saturated**" if, when kept at a uniform temperature, it can neither dissolve any more sugar nor form sugar-crystals. The higher the temperature of the solution,

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the more sugar can be dissolved by each part of water present. If the solution is evaporated to a smaller volume while at the temperature at which it is saturated, the sugar does not immediately crystallize out, but for the time being it remains dissolved and the solution is then said to be "**supersaturated.**" The purer the saturated sugar-solution and the greater the number of crystals there are in it which have already started to form, the more rapid is the separation of the excess of sugar over the amount required to saturate the solution and the more rapid is the growth of the deposited crystals. Impure sugar-solutions require considerable more time for the deposition of crystals; they must be much more strongly supersaturated before they will deposit crystals or allow them to grow, and this is proportional to the amount of non-sugars that these solutions contain.

If we designate by S the amount of sugar dissolved in one part of water at a definite temperature when the solution is saturated, and by S_1 that amount which at the same temperature is dissolved in the same amount of water in a supersaturated solution, then the ratio $C = \frac{S_1}{S}$ is called the **supersaturation-coefficient.** It represents how many times as much sugar there is dissolved in the supersaturated solution as in a saturated solution at the same temperature. This coefficient of supersaturation is of fundamental importance in the crystallization of the sugar, whether the latter be brought about by means of evaporation or by the working up of the massecuite. While all other conditions which affect the crystallization of the sugar, such as the viscosity, change with the temperature, this supersaturation-coefficient is independent of the temperature. It makes no difference, therefore, whether the boiling-down or other process used to effect the crystallization is carried out at a high or a low temperature, the most favorable coefficient of supersaturation for the formation of new crystals and the growth of those already formed is always the same (within the practical limits of temperature-changes) for sirups and juices of equal purity, although it varies with the purity, as has already been stated. Furthermore, the coefficient of supersaturation must be greater for the formation of

the grain and smaller, on the other hand, when the crystallization is favored by the presence of crystals in the solution.

For a well-regulated crystallization it is important that the supersaturation and the temperature which determines it should be the same at all points of the crystallizing mass. The supersaturation changes during boiling at first take place at the heating-surfaces, on account of evaporation, so that at these places stronger supersaturated solutions are readily formed which are likely to give rise to the formation of small crystals. On the other hand, at the places where the fresh sirup enters, the supersaturation is likely to be entirely eliminated with the solution of the crystals already formed, unless the sirup is immediately disseminated throughout the entire mass and mixed with the supersaturated sirup which surrounds the crystals. Consequently the greatest stress must be laid upon the importance of keeping a most thorough **circulation of the mass** in the vacuum-pan. The construction of the apparatus and the heating-coils should not offer any especial hindrance to such circulation; no method of construction, however, can bring about currents in the juice, but mechanical forces are required for this which are developed during the boiling by the ascending bubbles of water-vapor. As a matter of fact the evolution of these bubbles of steam is the slightest at that stage where it is most desirable that there should be a circulation of the mass, namely, at the end of the boiling. Arrangements by means of which at any time a regular motion can be imparted to the mass have proved very advantageous. Stirring-apparatus, screws, etc., have been found very satisfactory in this respect for the boiling-apparatus used for after-products. In the case of sirup-boiling such arrangements have not been used to any extent, largely because the available space is too limited, particularly in the older forms of apparatus; in the newer types stirring-arrangements are frequently found. The motion brought about by introduction of direct steam is very satisfactory. The bubbles of steam rising from the lower portions of the compartments stir the mass in all places and particularly at the heating-surfaces, which they can spread over much more satisfactorily than

could any stirring-apparatus, so that all local supersaturation or overheating is avoided. Consequently it is easy to avoid the formation of a fine grain, especially when the massecuite is kept in motion in this way by bubbles of steam.

In order to distribute the entering sirup throughout the mass as quickly as possible, it is introduced at the bottom and in fine streams so that it will rapidly mix with the mother-sirup, since it rises at once on account of its lighter specific gravity. This mixing is accelerated considerably if the sirup as it enters is very hot, with a temperature higher than that of the boiling mass. As the sirup enters the vacuum-pan, a considerable quantity of steam-bubbles is suddenly generated, thus accomplishing a rapid mixture with the remaining contents of the apparatus. The sirup should not be allowed to enter at a temperature lower than the boiling-point in the vacuum-pan, for it will then mix but slowly, while the massecuite will be cooled with the probability of forming a fine grain.

For the **formation of grain** in the vacuum-pan, therefore, it is necessary that the sirup should be supersaturated. As soon as the supersaturation has reached a certain degree, crystals begin to separate. It has been found advantageous to start the formation with the shock brought about by a sudden introduction of the sirup. The greater the supersaturation of the juice and the greater the motion, the quicker and richer will be the crystal formation. Under otherwise similar conditions it is necessary, therefore, to thicken the sirup less and to draw in less in proportion as it is desired to form less grain. However, the extent of the supersaturation may be quite different for the production of equal-sized grain, because in the case of continuous motion, which is brought about, for instance, by frequent opening of the sirup-valve, it is possible to form many crystals in very slightly supersaturated solutions, and conversely by infrequent introduction of the juice it is possible to form but little grain in strongly supersaturated solutions. The number 1.2 may be regarded as the lowest practical value for the supersaturation-coefficient for the formation of grain in sirups of from 90 to 92 purity; at a less supersaturation it takes too long before sufficient grain is produced, and there is always danger that the crystals

already formed will be redissolved by the introduction of fresh juice. The highest degree of supersaturation is with a coefficient of 1.5 to 1.6, for when more supersaturated too many crystals will be obtained by a single draught of the juice.

When, in one way or another, sufficient grain has been formed, further **boiling** is conducted in such a way that only these crystals grow and no others. As long as the crystals remain small and in consequence possess relatively small surfaces for the deposition of the crystallizing sugar, it is necessary to keep the surrounding sirup, the mother-liquor, but slightly supersaturated; for, as this sirup has still approximately the purity of the original thick juice. it retains the property of forming new crystals at a supersaturation of 1.2 by the motion brought about by the entrance of the sirup. During this stage of the boiling, therefore, the extent of the supersaturation should not exceed a coefficient of 1.2; it is safer not to even reach this limit.

The boiling from this point on can be conducted in two ways, either with an **uninterrupted or with an intermittent charging** of juice. In the former case the juice-valve is so set that exactly the right quantity of thick juice will be introduced in order to keep the mother-sirup permanently at the prescribed uniform supersaturation. The coefficient of supersaturation 1.1 is to be recommended, but at all events it should not be greatly exceeded at the start. In the case of periodic introduction of the juice, the valve is opened when the coefficient of supersaturation has risen to approximately 1.2 and enough juice is drawn in to nearly compensate the supersaturation, bringing the coefficient down to nearly 1.0. On no account should the mother-sirup be diluted to a point below the saturation-point, as otherwise the crystals already formed will be redissolved. As a general rule for both methods of feeding it may be said that in the case of slow boiling the upper limit of supersaturation must be kept lower than with rapid boiling.

Only in case too many crystals have been formed in the grain, or when later on fine crystals have been produced through a faulty conduct of the operation, should enough sirup be introduced to make the mother-sirup undersaturated so that the excess of

crystals will redissolve. Frequently such a dilution is brought about not by using sirup, particularly when it is very thick and concentrated, but by the injection of hot water, and this is sometimes necessary, chiefly towards the end of the boiling, in order to make a clean massecuite.

During the progress of the boiling the sugar-crystals are constantly growing and the purity of the mother-sirup becomes less. It is therefore not only permissible but even regarded as advantageous to bring the supersaturation-coefficient to 1.2 and even higher, until at the last drawing of the juice it reaches the value of about 1.3.

The art of boiling now consists only in being able to find out the proper coefficient of supersaturation and to maintain it in the mass by the external tokens, such as the **string-proof** and the viscosity of the massecuite, and by noting the temperature and the transparency of the crystals surrounded by sirup. Most operators boil with intermittent feeding of sirup, because this method is safer when the vacuum and steam-pressure are variable, as is usually the case. When, on the other hand, these conditions are constant and the juice that is being fed in is of uniform density, it is simpler to inject this juice uninterruptedly.

The steam must be so regulated that the evaporation does not take place too rapidly, and that after each introduction of the sirup the sugar actually has time to deposit upon the crystals present while the purity of the mother-liquor sinks regularly. The duration of the boiling can be shortened only at the expense of the yield, or by subsequent working up of the massecuite in crystallizers or coolers and so doing what was omitted previously. The rule should hold that boiling in grain should be conducted as slowly as possible, or at all events one boiling should require not less than six or eight hours for its completion, and those vacuum-pans which make it possible to boil in less time should not be regarded as superior, because it is not possible to replace the favorable action of time by any peculiar method of construction. In order to offset the temptation of boiling too rapidly, which occurs when using apparatus with large heating-surfaces, it is advisable to heat such forms of vacuum apparatus with steam of as low

pressure as possible, this being also economical both with regard to steam-consumption and sugar-loss.

The size of the vacuum-pan exerts no influence upon the quality of the boiling. It is possible to get just as good crystallization in a small apparatus as in a large one if both are properly constructed. The chief point is not to begin the formation of the grain with the apparatus too full. The pan should not be filled to more than from one-quarter to one-third of its total capacity, so that the crystals have time to grow during the further boiling.

A properly boiled massecuite, containing no excess of molasses-sirup, should yield a mother-liquor of from 80 to 82 purity If the duration of the boiling is continued for a very long time, it is possible to diminish to a considerable extent this purity, particularly if the apparatus be provided with a suitable stirring-arrangement. It appears questionable, however, whether it is desirable to produce such an extent of sugar-crystallization in a vacuum without the further introduction of sirup, and it is doubtful whether the further working up of the massecuite may not be more advantageously conducted in special crystallizers.

After the last introduction of the sirup the **finishing** of the massecuite begins. The manner in which this should be carried out depends upon the way the later processes are to be conducted. If the massecuite is to be discharged into large or small tanks, according to what is now regarded as the old-fashioned method,* it is boiled down until very hard and close, with a water-content of only about 5 per cent., or less. This carries the supersaturation of the mother-sirup so far at the end that even in the boiling-pan, or at all events as soon as it is discharged, a large number of small, new crystals are formed which, as the massecuite cools in the tanks, cause all the sugar that crystallizes out to deposit upon them or upon the larger crystals. Only a small part of these crystals which are formed at the last are of sufficient size to be retained in the centrifugal machines; the greater part are so small that they pass through the strainer with the sirup. The reason why it is desirable to form these crystals in the vacuum-pans is not so much to increase the yield as to obtain a satisfactory working of the cen-

* "Cold purging" method.

trifugals. If the massecuite were emptied out in a softer condition, there would be a formation of a mass of tiny crystals in the tank so great in number that they would scarcely permit any further growth. The mother-sirup would consequently be completely filled with a fine meal which would make the centrifugal work difficult if not impossible. This fine crystal meal deposits upon the large crystals or upon the strainer in the centrifugal, forming a film which is impenetrable to the sirup. When the massecuite is boiled stiff, there are fewer of these small crystals formed, and they are then large enough so that they do not form a film, but in so far as they are not retained between larger crystals are readily thrown off by the centrifugals.

For the ordinary direct mixing method* the massecuite must also be boiled down stiff for similar reasons. Consequently this method does not increase the sugar-yield, but frequently it is found to have exactly the opposite effect. The advantage gained by this method of work lies in the saving of labor and its cleanliness.

An appreciable increase in the yield can be brought about only by the new method of working up the massecuite in *crystallizers* in which the cooling and concentration of the mother-sirup are carefully regulated. In this case it is extremely important that the massecuite should not be boiled in such a way that new crystals will be formed in addition to the large ones that are already present. Consequently, even at the end of the boiling, the supersaturation-coefficient should not exceed 1.3. Since the mother-sirup, after the last injection of the sirup, already has approximately this coefficient, it would be useless to carry the boiling further if resource could not be had to some other means. After the last addition of the juice a little of the hot molasses, the purging of a previous boiling or from the crystallizers, is injected into the pan. Thereby the mother-sirup becomes diluted, and, if necessary, even to such an extent that any fine crystals which may have been formed redissolve and the boiling can then be continued slowly. When the supersaturation-coefficient of the mother-sirup has again risen to 1.3, in every case more sirup is added and this boiling with sirup

* "Hot purging" method.

continued for from one to two hours. The longer such boiling is continued, the more sugar will be deposited upon the crystals Since the movement of the mass is at this point very slight, owing to the slow evaporation, any arrangement for moving the mass is very useful, particularly when this is accomplished by the introduction of steam.

The sugar which crystallizes out upon the crystals already present during the **boiling with sirup** does not originate in the purgings added, but comes solely from the mother-sirup, and was in it before the beginning of the boiling, the purity being 80 or over. The sirup which is added invariably has a lower degree of purity, and at the conclusion of the work in the crystallizers it is again thrown off with the same purity at which it entered the boiling-pan. In the vacuum-pan it is used as a diluent to the massecuite, thereby lengthening the boiling operation; it also makes the massecuite work better, both in the vacuum-pan and in the crystallizer, by increasing the amount of the mother-sirup.

The difficulty of educating good sugar-boilers and exerting a control over them has caused the construction of a special form of control apparatus, with the aid of which the boiling can be carried out with greater certainty than by judging from not very trustworthy outer indications. This **control apparatus** depends upon the principle that the boiling-point of a sugar solution or sirup stands in an entirely definite relation to the concentration. The boiling-point of a sirup is higher in proportion to the amount of non-sugars that it contains and inversely proportional to the amount of water. For sirups of equal purity the rise in boiling-point with decrease in the amount of water present is, however, always the same, so that it is possible to prepare tables applicable to all cases for the juices and sirups. The boiling-point is not influenced by the fact that crystals are present in it, hence the boiling-point of a massecuite is always the same as that of the mother-liquor which surrounds the crystals. Again, the depth of liquid, which is considerable toward the last of the boiling, does not, as far as the thermometer will show, influence the boiling-point

appreciably if care is taken that the mass is kept sufficiently in motion.

If, by means of a thermometer, the boiling-point of the sirup in a vacuum-pan (the mother-sirup) be determined and the vacuum also read by means of a vacuum-gauge, it is possible, with the help of the tables given in the supplement to this book, to determine the boiling-point of water at the vacuum given. Then by subtracting this from the reading of the thermometer it is easy to determine the rise in boiling-point which has been brought about by the sirup. From the above data, with the aid of the boiling-point tables, it is a simple matter to calculate the amount of water present in the sirup in question.

Owing to the construction of the vacuum-pan, the immediate practical utilization of the result is attendant with more or less difficulty. The determination of the amount of water present (or the amount in degrees Brix in the case of an incomplete apparatus) is of itself of but very little assistance in the factory. Separate tables should show the amount of water that the sirup must have for every particular sirup, and for the supersaturation at the particular point of the boiling; and when these are graduated on a suitable scale, the boiling can be carried out without difficulty. It is much more simple to have the control apparatus show directly upon the scale the temperature that the massecuite should have at every stage of the process. This latter construction, which permits the results to be read off with the greatest readiness, is especially suited for the boiling down of the first massecuite.

With the aid of such an apparatus any trustworthy workman can learn in a short time how to conduct the boiling and make uniformly good sugar. This control is also particularly useful for the superintendent or manager of the plant. When the ordinary method is being used any one who does not remain constantly at the boiling-pan or who has not served a thorough apprenticeship can tell very little, if anything, with regard to whether at any given time the boiler is conducting the operation properly; consequently in many factories the sugar-boiler is an exceedingly independent official.

An end to this certainly not very desirable state of affairs is brought about by the introduction of the control apparatus.

Destruction of sugar during boiling seems practically out of the question, or at least under the ordinary conditions. Since, on account of the previously mentioned grounds, the object is to impart a sufficient motion to the massecuite in the boiling apparatus and at the heating-surfaces (and as a matter of fact this can be accomplished in almost every case), a high temperature will not prevail throughout the most of the mass even when the heating is in the old-fashioned way with direct steam. In the case of very tall apparatus there may be a loss in sugar of from 1–2 per cent. when such are not provided with mechanical stirrers, and in the case of stiff massecuites it is possible that the latter may be overheated a few degrees on the heating-surfaces. But even in such unfavorable places, which as a matter of fact are only met with in poorly constructed pans, there can be no very great overheating above 85° to 90° (185°–194° F.), under the vacuum of 55 to 65 cm. (21¾ to 25½ in.) which ordinarily prevails, except in those cases where the massecuite is burned or scorched at one place. At such temperatures it is impossible that there should be a perceptible decomposition of sugar in an alkaline massecuite. Even when we assume that portions of the massecuite have temporarily a higher temperature when in contact with the heating-surfaces, this temperature can never be as high as the steam used for heating, and the latter has a maximum temperature of from 115° to 120° C. (239° to 248° F.), at which it is impossible to decompose perceptible amounts of sugar. Statements to the contrary which have sometimes been recorded can be true only under extraordinary conditions, or the experiments were made with inaccurate methods of observation, so that they are lacking in proof. It must be remembered, furthermore, that at the very time when the possibility of scorching is the greatest, on account of the motion of the mass being the slightest, three-quarters of the sugar has crystallized out and will then not suffer at the prevailing temperature. If a perceptible amount of sugar is decomposed during the operation, the alkalinity of the sirup must increase considerably, for there will be 0.4 of a part of

potash and 0.25 of a part of lime set free for each part of sugar decomposed. Such an increase in alkalinity is, however, never met with, and the only possible indication of any decomposition is in a slight decomposition of the non-sugars and a slight amount of ammonia evolved. If, however, the sirup boiled is neutral or acid, it is possible, by a long-continued boiling and by high temperatures of the masses and heating vapor, to decompose considerable amounts of sugar.

During a normal boiling there are no **mechanical losses** of sugar. Small, fine drops are never formed from the viscous mass to be carried off mechanically with the vapor; as the bubbles of steam arise and break on the surface of the boiling mass large pieces of the latter are loosened and thrown up, but they immediately sink back on account of their weight. When the sirup is thinner it is indeed possible for tiny drops to form; but then there is greater empty space above the liquid, and as the latter becomes more viscous this need not be so large. There should always be one or two yards of empty space above the maximum filling In exceptional cases it is possible that there may be considerable foaming. This is caused sometimes by the nature of the juice, or in the case of a normal juice it may be brought about by suddenly increasing the vacuum, when, for example, the condensers are not working right (owing to lack of water) or the vacuum is increased at the air-pump. The massecuite is then at a temperature higher than corresponds to the boiling-point of the greater vacuum, and the excess of heat is suddenly given up by the formation of a large number of bubbles of steam. In such cases great care is necessary to prevent some of the massecuite from getting into the vapor-pipes and being carried to the condensers. Diminishing the vacuum by allowing considerable air to enter by closing the vapor-valve and then slowly opening it, and the introduction of a little grease until boiling becomes uniform again, are the means employed to prevent foaming.

Sugar-losses may be caused by leaky coils or heating-tubes, and this source of trouble is more serious here than in the multiple-effect evaporators, because in such cases some of the massecuite may

enter the heating-space or get into the condensed water with each filling of the apparatus. On this account it is desirable to test the condensed water frequently to see if any sugar is contained in it, and particularly when the apparatus is first put into use.

Larger leaks at the heating-surfaces make themselves evident by the fact that some of the condensed water enters the apparatus during the boiling, whereby the formation of the grain and in fact the whole process is very much lengthened.

One of the **worst troubles** that can take place during this part of the process is the so-called **"heavy boiling,"** which, according to the degree, may be made manifest by a lengthening of the process or even an entire cessation of the boiling. This is met with in working up juices of low purity made from unripe or decayed beets. The real causes have never been entirely satisfactorily explained. Some claim that the difficulty in boiling is due to the presence of lime salts, which are always present to some extent, while others believe it to be due to the presence of organic constituents which are present in large quantities compared to the amount of ash, and in particular those substances which result from the pectic substances present in the beets. Both of these views agree in so far as there are always large amounts of lime salts present when there is an increase in the organic matter owing to the poor quality of the beets.

The increase in the amount of lime salts present does not, however, of itself cause the difficult boiling. Such lime salts as are formed, for example, by the decomposition of the invert-sugar and nitrogenous matter by caustic lime, do not exert an injurious effect upon the boiling; these lime salts in fact are not molasses-forming to the extent that the organic potassium salts are. It is accordingly clear that all lime salts of themselves cannot be looked upon as the cause of the difficult boiling, and any conclusion with regard to the amount of lime present and the effect upon the boiling is likely to be misleading.

Difficult boiling is, therefore, caused by an excess of lime salts or by certain non-saccharine organic matter. These injurious, organic non-sugars are at all events those which were

first dissolved during the diffusion process from unripe beets or those of bad quality. The amount of these non-sugars increases if the work is conducted slowly and at high temperature. Consequently, to a certain extent this hard boiling may be avoided, or at least the difficulty may be lessened, if the diffusion be done quickly. The greatest amount of these non-sugars is dissolved naturally in the sweetening off of the battery, and consequently the last boiling of the week will show this phenomenon of hard boiling to the greatest extent.

Sirups which are insufficiently saturated with carbonic-acid gas are always boiled down with difficulty; for this reason, also, the juices should be carefully saturated. Since lime sucrate is so injurious upon the boiling down, it seems reasonable to assume that of the different lime salts only those can cause the hard boiling which are combined with organic acids of high molecular weight, and it is to this class of acids which the pectic substances belong.

As a **preventive of hard boiling,** disregarding the changing of the diffusion work, *the addition of soda* or acid-sodium sulphate has been recommended in order to effect the transformation of the lime salts into the corresponding sodium ones. Even if this remedy in some cases does not prove of much help, yet it is always advisable to try it. The sodium salts are added to the thick juice, or, better still, to the thin juice, in order to be able to filter off the precipitated carbonate or sulphate of lime. It is not necessary, however, to convert the entire quantity of lime salts present into sodium salts, but it suffices to add from one-quarter to one-half of the theoretical amount, for apparently the injurious lime salts are acted upon first. In fact it is not possible to decompose all the lime salts with any excess of soda.

Another remedy, which in all cases accomplishes good, is the *artificial movement* of the mass in the boiling-apparatus, and particularly stirring that is brought about by introduction of steam which enters at the bottom of the apparatus through a spraying-arrangement. In this way any amount of bubbles of steam may be introduced and driven through the mass, thus giving it a uniform motion, so that finally the heat-transference and the crystallization take place satisfactorily.

When the hard boiling occurs, then, owing to the viscosity of the mass and the irregular heat-transference, there is usually a **violent foaming.** In this case also, the introduction of live steam neutralizes the cause of the foaming and is the best remedy; it should be tried in all cases before resorting to the use of grease or oil.

By improper handling of the pan it is possible in some forms of apparatus that another difficulty may be met with, and that is the formation of *hard* **lumps in the massecuite.** These lumps are formed chiefly at the beginning of the boiling and in those forms of apparatus where the heating-surfaces are not entirely covered with juice at this stage. The concentrated juice then spatters against the upper portion of the heating-surfaces (steam-coils), the drops adhere firmly and sugar crystallizes out, remaining together with the sirup adhering to the heating-surface, and particularly when these coils retain steam on account of the valves not being perfectly tight. The spattered lump adheres so firmly at some places that it cannot be loosened even although it may subsequently rest in the centre of the boiling massecuite. Naturally the adhering mass cannot be dissolved off, as it is constantly surrounded by supersaturated juices, and if steam is then gradually introduced into the upper heating-surfaces it burns fast to the steam-coil, forming hard scale, fragments of which of considerable size may be found at the corners of the coil-hangers, or at the flanges. This scale shows a crystalline cleavage. By reason of the changes in temperature, and particularly as the heating-surfaces first warm up, the pieces crack off and mix with the massecuite and the sugar, of which only the larger fragments are purged out. Hard lumps can also form in the lower parts of the pan when the coils are placed so closely that they prevent movement of the massecuite and allow it to burn on to the steam-coils.

The fact that the massecuite contains such lumps and scales is recognized at the time, as they have the shape of the coils or tubes inside the apparatus. Those scales that are formed in the upper part usually show a finely crystalline nature, while those lower down, which have been formed between the coils during thickening of the massecuite, show a more coarsely crystalline structure.

This formation of scales is naturally best avoided by using a vacuum-pan with properly built heating-surfaces. In those forms of apparatus with vertical tubes, which from the very beginning are covered with juice, they are never formed. In apparatus having coils and similar heating-arrangements they are formed to a greater or less extent; it is then necessary to take care that they do not reach the sugar. To prevent this, all deposits upon the coils must be dissolved off after removal of the massecuite at the end of each boiling and before the introduction of a new lot of juice. It is not advisable to attempt to dissolve these deposits by means of the sirup itself, for as a rule the latter is concentrated so rapidly that it has little if any solvent action. The apparatus should be steamed out until it is absolutely certain that every bit of deposit upon the coils has been removed. This is best accomplished by placing perforated steam-pipes over those places where the deposits are likely to form, in such a way that the steam will be directed toward them. Frequently this treatment results in some of the scales being broken off by expansion; in such cases it is advisable to separate the steaming water containing these sugar residuals and send it to the sirup, or allow it to run through a strainer to remove the lumps.

The introduction of direct steam during boiling acts very advantageously in preventing the formation of these lumps and scales in the lower part of the apparatus. But even then, in case the vacuum-pan is of too close construction with coils or tubes packed together, it is necessary to thoroughly steam out after each boiling, and this is best done by letting in steam from beneath as well as from above and through the coils.

In other respects, also, a *good* steaming out is advantageous at the completion of each boiling. In all cases a little of the massecuite is certain to remain adhering to the more prominent parts of the apparatus and the crystals are only partially dissolved, if at all, in the sirup which is next treated; in case the juice is already strongly concentrated, there will be a certain amount of coarser crystals in the presence of the newly formed and finer ones, and the presence of the former is by no means desirable. By steaming

out the pan, all of the massecuite remaining in the apparatus is either made to flow out of the pan, or if it remains, it is in a dissolved condition.

It is particularly desirable to arrange to have that part of the pan in the vicinity of the sight-glasses well steamed out, for these glasses always have a little offset, which makes a hollow on the inside that is particularly likely to be filled with massecuite, and unless the apparatus is provided with an especial arrangement, this is likely to retain undissolved sugar both from the steaming-out process and from the next change of sirup. Clean sight-glasses are especially necessary for the work, so that it is well to blow a fine stream of water-vapor against them after each boiling until they are perfectly clean. When the holes in the steam-pipe are made so small that the steam escapes in a very fine spray, there is no danger of breaking the glass.

The diluted massecuite which flows from the apparatus during the steaming-out process, and which if the process is continued for some length of time eventually forms a thin sirup, is in the case of tank-work emptied into a separate tank; when crystallizers are used it serves for the dilution of the massecuite, which is usually obtained in a too viscous condition. It does not seem always necessary to collect separately the juice obtained in the steaming-out process, because when the mother-liquor is diluted by it the supersaturation-coefficient is still as high as is necessary for satisfactory completion of the process.

With regard to **variations** in the customary methods of conducting the boiling-in-grain process, there are practically none, if we disregard individual *tricks* of the sugar-boilers which are usually not essentially different and often apply **only** to the particular factory in question. Perhaps it might be mentioned in this connection that, to obtain extra-large crystals, the practice is to divide the finished strike of one pan between two pans just before the introduction of the last portion of sirup, and work up the two halves separately, or let half run out of the pan and continue the boiling of the rest till the pan is full.*

In some factories it is considered best to make but **one raw-**

* This is known as making a "cut."—TRANSLATORS.

sugar product (firsts or granulated) and the **molasses.** In such cases it is not permissible to mix any sugar that subsequently crystallizes out, with the first product, as is sometimes done in certain countries to the detriment of the quality of the product manufactured. It is desirable in these factories always to begin the boiling process with sirup and later on, by the addition of sirup and long-continued boiling, to carry the work so far that in the crystallizers all of the sugar possible is obtained, with the mother-sirup entirely converted into molasses.

The usual method is to conduct a few boilings at the start in the customary manner. When enough of the sirup that drains off has been collected, the sirup is boiled down to a finely granular masse-cuite and in such a way that the pan is approximately half-filled, then sirup is introduced and the boiling is continued by the method which will be described later on for the boiling of "after-product" sirup to grain. Such a boiling should require at least 20 to 24 hours, while at least 4 days are necessary for the work in the crystallizers if an actual molasses is to be obtained. The masse-cuite obtained in such a way is as coarsely granular as a normal No. 1 product, and the sugar-yield is equally good, so that in these respects it is just as good a product as that obtained from the previous boilings. With regard to the refining of the product however, there is this difference: it is not possible to obtain white crystals after centrifugation. If such a sugar be mixed with the product obtained in the usual way, and if, as is the case, the dark-colored product is not valued as highly, it appears very doubtful as to whether it is advisable to work in this manner. It is a question to be determined only by a careful calculation in which all the different factors are taken into consideration.

In order to conduct the boiling operation according to this last-mentioned plan it is necessary that the sugar-boiler should be very skillful and absolutely trustworthy. In order to obtain perfectly uniform results it is necessary to make use of a boiling-control apparatus provided with the necessary scales.

CHAPTER XVI.

WORKING UP THE "MASSECUITE."

In emptying the massecuite into coolers or an ordinary mixer, a regulated crystallization of the sugar is out of the question. The only precaution to be taken is to prevent too rapid cooling. As has already been mentioned, the sugar now crystallizes to some extent upon the large crystals already formed, but also upon crystals formed during the boiling, discharging, or cooling, and which are so small that only a small portion of them can be recovered in their present size. The chief object of the process, namely, an increase in sugar-yield, cannot be accomplished by tank-work or by mixers. At this stage the only aim is to bring the mass to such a condition that it is suitable for centrifugal purging.

In the **cooler** (tank) **process,** the sugar is expelled from the coolers by compressed air in the form of blocks of massecuite which are more or less hard and brittle according to the method of boiling and the rate of cooling the massecuite. It is broken up in the small mixers and mashed with more or less sirup. According to the extent of the cooling that the mass has undergone, hot or cold, thick or thin sirup is used for this purpose. If a large number of mealy crystals have been formed so that it will be hard to centrifugate the mass, it is necessary to add sufficient hot sirup to redissolve these fine crystals. There is in fact no better criterion for regulating the amount of sirup added to the massacuite than the ease of working in the centrifugals. Usually the workman is paid "by the piece," and it is on this account that the general tendency is to add too much, too thin, or too hot sirup.

In the *ordinary method* of **hot purging** there cannot be a proper regulation of the temperature, although this is the chief requisite for good crystallization. The favorable temperature for centrifugation is from 40° to 50° C. (104° to 122° F.), and the massecuite is brought to this temperature as quickly as possible by adding water or dilute sirup until it is sufficiently mobile. Working in mixers has the advantage over cooling-tanks that it permits cleaner work in the sugar-house. On the other hand, the yield by the other method is greater and the quality of the product poorer. By either method of working, however, the molasses seldom has a purity less than 78 to 80 per cent.

Rational working up of massecuite can only be carried out when this has been properly boiled with sirup and when the temperature and concentrations have been systematically regulated. The sugar-yield from the massecuite can only be increased to a certain extent, and this increase is in proportion to the diminution in purity of the sirup which drains off from it.

The working up of the massecuite depends upon the principle that from every sirup which has not been too strongly concentrated the sugar crystallizes out satisfactorily only when there are a sufficient number of exciting crystals present, and, furthermore. upon the fact that a solution of sugar which is saturated or slightly supersaturated at a high temperature becomes strongly supersaturated upon cooling. The aim is, therefore, to conduct the cooling in such a way that the supersaturation coefficient of the mother-sirup under no conditions exceeds the limit above which there is a tendency to form new crystals, while on the other hand the cooling should take place rapidly enough so that the coefficient remains at least 1.05–1.10; because if the extent of supersaturation is slight the crystallization takes place altogether too slowly. Crystallization takes place to some extent of its own accord after the massecuite has been discharged from the vacuum-pan, because the massecuite is filled with more or less strongly supersaturated mother-sirup and is only brought about by cooling which increases the low supersaturation-coefficient till the original value is practically attained. The chief requirement for the whole work is

that the entire massecuite should be maintained at a uniform temperature and concentration, or in other words that the mass be sufficiently agitated.

The prevailing idea in the use of stirrers and other appliances in "crystallization in motion" is that this stirring is a direct cause of crystal formatiion. This view is entirely wrong. The sugar particles directly in contact with a sugar crystal are the only ones which enter in its growth. When this film becomes exhausted, and hence less concentrated, a diffusion begins between this and the adjacent sirup film.

The more favorable the conditions for this diffusion the more rapidly crystallization goes on. Since the greatest impediment to diffusion is viscosity, any conditions which lessen viscosity hasten crystallization. The viscosity increases greatly in proportion to the extent of supersaturation and to the drop in temperature. Hence the use of a moderate supersaturation and proper temperature is of the utmost importance for good crystallization.

Stirring has no effect on any of these conditions. It does bring about equal temperature conditions and in large degree an equal density throughout the massecuite. This action is also of great importance because it hinders the formation of second grain and keeps the grain already formed equally distributed through the massecuite. Therefore, stirring only partially aids crystallization, which is entirely dependent on a diffusion action.

To accomplish this in working up massecuite crystallizers are used. They usually consist of horizontally placed, closed, cylindrical retainers which are provided with a double mantle or other arrangement for heating or cooling the contents, and a suitable stirring-arrangement inside, or they themselves revolve upon an axis. The massecuite is transferred from the boiling-pan to the crystallizer by gutters in case the former is above the latter; otherwise the massecuite is removed from the vacuum-pan by compressed air and forced up to the crystallizer, or by means of a vacuum in the latter is sucked up into it. It is not recommended to pump up first product on account of too great cooling in the pipes or foaming.

There are two methods of using crystallizers. By the first method the massecuite is filled with fairly strongly supersaturated mother-sirup, so that the supersaturation-coefficient is about 1.3. Such a mass contains from 6 to 7 per cent of water and should not be cooled much at first, but it must be kept at the original temperature of 75° to 80° C. (167° to 176° F.) for several hours; the reason for this is that the supersaturation is so great that new crystals would immediately form if the massecuite were cooled. When the crystallization has proceeded to the point when the supersaturation coefficient is reduced to 1.1 to 1.2, the mass is slowly allowed to cool. If at the end of from 18 to 24 hours the temperature has been lowered to about 60° C. (140° F.), enough thin dilute sirup must be added to render the mass sufficiently fluid so that it can be centrifugated. The work in the crystallizer is complete when the temperature has been reduced to 55° C. (131° F.).

Since there is more danger of making mistakes when the attempt is made to work with stiff massecuites, it is usually preferable to work with thin ones. Of course it is possible to boil such a massecuite until it has a supersaturation-coefficient of 1.3, and this is always advisable. After discharging the vacuum-pan the condensed water from steaming out is allowed to run upon the massecuite in the crystallizer, or a little dilute sirup is added so that the supersaturation-coefficient of the mother-liquor sinks to about 1.15 to 1.2. Such a mass contains from 8 to 8½ per cent of water and can be cooled at once and relatively rapidly. At the end of 15 to 20 hours it may reach the temperature of from 45° to 55° C. (113° to 131° F.) without the formation of any new crystals or necessity of further dilution.

Naturally it is not possible to obtain as great sugar-yield in the last-mentioned case as when undiluted and stiff-cooked massecuite is worked up. In working up these lighter massecuites, ordinarily the sirup that drains off has a purity of but 75 per cent, and the purity is less only when the boiling with sirup is long-continued; in the case of undiluted massecuites, on the other hand, it is possible to reduce the sugar in the sirup to less than 70 per cent. To be sure, this requires greater attention, and in case the

proper attention is not paid, massecuites are obtained which are very hard to centrifugate; this difficulty is then only overcome by heating and diluting, and during this process so much sugar is dissolved out that the yield is greatly lessened.

A method of working up massecuites which on its face appears quite different is, in principle, essentially the same, and that is the working up in the so-called **"Kochmaischen."** These are air-tight crystallizers into which the mass after being boiled down in the pans can be transferred under vacuum very slowly and with the proper addition of dilute sirup can be boiled further and finally allowed to cool off. This apparatus, therefore, acts at the beginning as a vacuum-pan, with very small heating-surfaces, and later as a crystallizer.

When such an apparatus is used, the crystallization of the sugar is brought about at first merely by means of a slow evaporation, and only towards the end by cooling. Theoretically, the evaporation should take place so that the supersaturation coefficient of from 1.2 to 1.3 is always maintained, and if it were possible to accomplish this in practice, there is no doubt but that this method would furnish a most rapid crystallization and would be preferred to the use of crystallizers. As a matter of fact, however, there is no way of determining whether the proper supersaturation prevails. In almost every case new crystals are formed which must be afterwards redissolved by thin sirup and in this way, naturally, the whole continuity of the process is disturbed. Consequently it cannot be said that better results or quicker working are obtained with this form of apparatus.

No matter which method of working up massecuite is used, crystallization never takes place as rapidly as in the vacuum-pan, because the mother-sirup already has a lower purity and this constantly becomes less. It does not seem advantageous, in the case of normal working, to carry the crystallization of the sugar from the mother-sirups too far in the manufacture of first product. This would require too many vacuum-pans with stirring arrangements and of crystallizers or "Kochmaischen." Usually it is considered satisfactory to stop when the sirup that runs off con-

tains 75 per cent of sugar; only a few factories attempt to reduce the purity to 70 or 72, while a great many stop when the sirup contains more than 75 per cent of sugar. For making good raw sugar which leaves the centrifugals perfectly white and can be easily refined, the purity of the sirup should not be lowered too much.

Indeed, the purity of the sirup that drains off depends not only upon the method of working and upon the duration of the crystallization process, but also, not inconsiderably, upon the *amount and size of the crystals present.* The finer the crystals are, the more exciting faces are present to hasten the crystallizing of the sugar and consequently the more rapid is the crystallization. Whereas one kilogram of very coarse granular raw sugar presents a total outer surface of crystals amounting to about 3 square meters, the same weight of fine crystals may have a surface of about 7 square meters. If it be desired simply to obtain a speedy crystallization of the sugar, without paying any attention to any other particular, the aim should be to form a large number of fine crystals. The preparation of a coarsely granular sugar with a correspondingly equal desugarizing of the mother-sirup always requires relatively more time, and consequently more space to be taken up by vacuum-pans and crystallizers.

CHAPTER XVII.

THE CENTRIFUGAL WORK.

IF the massecuite of the first product has been properly boiled down, the separation of the sirup from the sugar crystals in the centrifugal machines presents no difficulties; this part of the work then becomes the simplest operation in the whole process.

The **centrifugals** themselves are either *suspended* or *standing*. In Germany the latter type is used almost exclusively, although in certain respects the former has advantages. Whereas formerly the drums of the centrifugals always had a diameter of about 800 millimeters (30 inches) and for one filling in the neighborhood of 80 to 100 kilos of massecuite was sufficient (175 to 220 lbs.), at the present time centrifugals of much greater diameter, with a capacity of 150 to 500 kilos (330 to 1100 lbs.) and arranged for discharging at the bottom, are in use. In this way a great deal of labor is saved. Experiments in the attempt to make a continuous centrifugal have miscarried.

For the best centrifugal work some attention must be paid to the holes of the strainer. To prevent the strainer from lying flat against the walls of the drum, thereby making a large part of the holes or slits inactive, there must be placed under each strainer another wide-meshed sieve, thus giving the necessary interspace between the strainer and the sides of the drum. The holes or slits must be made as fine as possible, small but not so small that they are stopped up by the crystals. The suitable size must be determined by experiment in each separate factory. There does not seem to be any special advantage in having these holes or slits of conical shape, and this is also true with regard to many other of the so-called improvements; the chief requisite is the

shape and size of the holes on the inside. Smooth strainers made of sheet metal are usually preferred to those made of cloth.

The introduction of the **massecuite** into the centrifugals, when the mixers or crystallizers are above them, is effected by means of spouts or wagons; if the mixers are at the same level or lower, the massecuite is first carried from the crystallizer, which is made air-tight, either by means of compressed air, or by peculiarly constructed pumps, into an intermediate mixer at a higher level, whence it runs by gutters or spouts to the centrifugals below.

The wagons have the advantage that the massecuite is cooled but little and that each centrifugal can be filled with an accurately measured amount of massecuite, although the work is not so clean as is the case when spouts are used, each of which is provided with a discharge-gate above the centrifugal. Even stiff massecuites will flow sufficiently well in such spouts, although it is very practical to place a shaft with short stirring-arms in such a way that the mass is slowly and steadily stirred, thus preventing a deposition of sugar crystals upon the bottom. It is also very advisable to provide the mixer with a steam-jacket, although it is rarely necessary to heat the massecuite in the mixers during the normal process of manufacture of "firsts," but it is sometimes desirable in the case of massecuites which do not work well in the machines, when it is necessary to keep them in the gutters for some time. If the centrifugals are filled when not in motion, as is usually the case with "firsts," it is feasible to use an indicator on the inner cone of the machine to determine when the centrifugal has been properly charged. The operator is usually able to judge the proper amount very accurately with his eye, even when the centrifugal is in motion, as is frequently the case in working up "seconds." When the massecuites are easily centrifugated the sirup is removed from the crystals before the machine has attained the normal number of revolutions per second. Naturally, crystals lying directly against the strainer retain less sirup than those in the interior, but this difference is very slight, and during discharging of the centrifugals and the transportation of the sugar-product the latter usually becomes uniformly mixed.

When the centrifugal work becomes difficult it is necessary to drive the machines for a considerable length of time at their maximum velocity. In such cases some portions of the contents are even then found to be badly purged. It is extremely hard to remedy this while the massecuite is in the centrifugal, or at any event without incurring considerable sugar-losses, and it is far better to aim at preventing, rather than remedying, the trouble. The difficulty is usually caused by the presence of a fine crystal meal, which is formed in more or less quantity by a crystallization process improperly conducted.

There are, to be sure, certain other causes of **difficult or very slow centrifugal work,** such as foamy stirring and the massecuite cooling and graining out too much.

The massecuite can be stirred until it becones filled with *foam,* both in the crystallizers and in the mixers, if the arms or wings of the stirrer project in such a way that air is stirred into the sugar mass. To prevent this the stirring arrangement should be entirely covered with the sugar. When emptying a crystallizer the stirring-arms will, however, reach out into the air, but it is not advisable to stop the stirring, because in that case crystals will settle out on the bottom, and it will then be impossible to start stirring again; it is, therefore, better to stir very slowly at this point, so that an appreciable amount of foam will not be formed. If the stirrer then makes one-half to one, or at most one and one-half revolutions per minute, it is sufficient to maintain a uniform temperature throughout the mass. It is easy to understand without explanation why the foamy masses are difficult to centrifugate properly, because the lighter and foamy sirup deposits upon the crystals, forming a tough film which cannot be forced through the sugar by means of the centrifugal force.

It is also advisable to avoid *cooling the massecuite* too far. The point of effective cooling must be regulated first of all, according to the extent of supersaturation, which in good work is always small; it is dependent chiefly, however, on the amount that the mother-sirup is desugarized, *i.e.*, its purity. The less this is, the higher the purging temperature will have to be, since

the viscosity of a sirup of low purity increases much faster as the temperature drops than in a sirup of higher purity having an equal supersaturation.

Massecuites having a sirup of high purity can be cooled to 40–45° (104–113° F.), but those having a much desugarized sirup will purge better at 50–60° (122–140° F.). Cooling while on the way from crystallizers to centrifugals is always bad, and should be provided against by suitable contrivances.

However, it is only in the case of excessively cooled massecuites that the viscosity is the cause of the bad working or prolonging the time required in centrifugation. In the case of warm massecuites it plays no part at all, except when a finely crystalline meal is present. This *crystal meal* separates out upon the larger crystals as in the case of the foamy sirup through the action of centrifugal force. When the centrifugals act badly there usually rests upon the strainer a layer of sugar which has been more or less satisfactorily drained of its sirup, then follows a tough layer of tiny crystals cemented together, and, finally, there is more or less of the sirup which has been unable to penetrate this layer.

If such massecuite has been made by improper boiling there is nothing else to do but dissolve the meal in the crystallizers or mixers by the addition of very hot or very dilute sirup. If this is done very carefully there is little danger of dissolving out any great amount of sugar from the larger crystals. In working with crystallizers it is, furthermore, always possible to regain the greater amount of the dissolved sugar by a properly conducted cooling process.

The suitability of the massecuite for centrifugation depends on the amount of this crystalline meal and its fineness. A little of this meal or fine crystals is present in every case, as can be easily proven by the microscope. If it be found that the massecuite is unsuitable for centrifugal work after it has been introduced into the machines there is nothing to do but introduce steam during the purging which redissolves the finer crystals and heats the sirup. It is preferable to introduce steam between the drum and the mantle rather than from inside the drum, because

in the latter case the steam acts more slowly and uniformly, so that much sugar is not dissolved off from the large crystals. It is certain that the sugar-losses brought about by such a treatment in the centrifugals are greater and the yield smaller than when the meal is removed by treatment in crystallizers or mixers.

CHAPTER XVIII.

RAW SUGAR AND ITS PREPARATION.

Raw sugar is obtained simply by the centrifugation of the massecuite. In the case of "firsts" the centrifugals are filled while not in motion, and as much massecuite is placed in them as their construction and strength will permit working satisfactorily. The greater the quantity of the massecuite introduced the more raw sugar will be obtained from each centrifugal, because a very considerable part of the time is spent in filling and discharging, and this time is practically the same irrespective of the extent of filling. In the manufacture of raw sugar, therefore, centrifugals of large diameter and capacity are suitable, and, if these are provided with an underdischarge, the amount of labor can be greatly lessened.

Raw sugar, as it comes from the centrifugals, consists of pure or almost pure sugar-crystals and a sirup whose composition is identical with the purgings. Evidently this sirup is the same as that which surrounded the crystals of the massecuite, and hence at the finishing temperature of the pan was still more or less supersaturated. This supersaturation increases also as the sugar cools in storage and still more by its drying in the carriers and the sieves.

It would seem logical that crystallization out of this sirup would continue while the sugar was in storage, as the conditions are excellent for a rapid and extensive crystal formation from the

supersaturated sirup, there being present a great excess of crystal nuclei, 6–12 times the weight of the sirup. The average thickness of the sirup film on the crystals is only 0.01–0.02 mm. (.0004–.0008 inch), a very minute layer, which would naturally lead one to assume that an after crystallization always occurred.

As a matter of fact, this crystal increase never is found. Sirup washed from raw sugar crystals by reliable methods is unchanged and shows exactly the same purity as the purgings, namely, 70–80, while its supersaturation coefficient has risen at the room temperature from 1.5 to 1.8.

There is no explanation for this remarkable phenomenon other than that the great viscosity of the sirup, increased by the supersaturation induced by the rapid cooling, prevents crystallization in spite of the presence of so many crystal nuclei.

A proper yield of raw sugar can be obtained from any good massecuite, as the only difference between one and another lies in the proportion of crystals to sirup.

The question as to the advantage of preparing **raw sugar of a greater or less purity** depends upon the prices which can be obtained for each grade. When the increase of the price for one degree of greater purity is more than one per cent of the bottom price a calculation will always be in favor of producing the better sugar. At the same time it must be remembered that in the preparation of the better-quality sugar more centrifugals are required and more final sirup is obtained; in other words, it must be considered whether the factory is adapted to the production of the product desired.

The quality of the sugar, or, in other words, the readiness with which it can be converted into salable products, depends not only upon the percentage of sucrose which it contains but also upon its outward characteristics, and in particular upon having the crystals sharp, brilliant, and of uniform size and whiteness, and the adhering sirup not too viscid and free as possible from tiny crystals of sugar. For the preparation of certain grades of sugar quite large crystals are required. It would seem desirable that all of these requirements should be considered in estimating the

value of a given raw product, but up to the present time no method has been discovered which will give results that are satisfactory to the trade. Paying for the sugar according to the percentage of ash by no means meets the actual requirements, for the yield in refined sugar depends not only upon the ash but also upon the organic non-sugars, and chiefly, in fact, upon the nature of the sugar itself. All propositions, however, in the nature of offering a more just valuation of the raw product have miscarried, on account of the unreliability of the methods of examination or the uncertainty of results obtained by analysis, so that the relatively more accurate determination of the ash has been deemed most satisfactory by the trade and has not been given up.

Good raw sugar which is suitable for the preparation of the grades in daily use will always be obtained if the juices are good, well boiled, and the working up of the massecuite is carried out with care, as shown by its passing well through the centrifugal machines at normal temperature. A raw sugar which is centrifugated with difficulty is always hard to refine, especially when boiled by taking in large quantities of reworked sirup and where mother-sirup is highly desugarized.

The color of raw sugar is not always a reliable indication of its value; although in general a lighter sugar will be preferred, yet it ought to be determined whether this is the natural color, or whether it has been produced artificially by means of decolorizing agents. Furthermore, the color of the sirup which causes the color of the raw sugar is of less importance than the color of the crystals themselves, and not infrequently it will be found that crystals which are coated with dark-colored sirup are really lighter than those coated with a light-colored sirup. If the crystals are not pure white they are better when of a pale yellow than a grayish tone, for in refining the yellow color is readily removed by the charcoal or covered up by bluing, so that the finished sugar is of a better shade than when the raw sugar is gray. The cause of the gray coloration is a slight iron-content of the juices which results from an unsatisfactory carbonatation. Iron salts pass into solution or remain dissolved when the second carbonatation is some-

what incomplete so that some calcium sucrate remains in solution, or when the carbonatation is carried too far. Juices which when thick or thin were saturated to an acid reaction will always contain iron, and sugar prepared from them frequently offers serious difficulties to the preparation of a pure white refined product. Hence gray sugars are always acid to phenolphthalein. Carbonic-acid gas containing hydrogen-sulphide gas is also said to cause the formation of a gray sugar, but, if so, this is due to the presence of a small amount of iron sulphide remaining dissolved in the juices.

It is also a requisite of good raw sugar that it **does not undergo change in storage.** This is the case when the sugar shows an alkaline reaction with phenolphthalein, when it is free from the germs that cause sugar to invert, and also free from easily decomposable organic non-sugars. Alkaline massecuites are always obtained from well-defecated and alkaline juices, and consequently yield a sugar which keeps well if the sirup is sufficiently supersaturated and remains supersaturated while kept in dry and cool places; for, in such cases, bacteria cannot very well get into the sirup or still less can they develop in it. When, however, a raw sugar is stored, which contains so much moisture that the sirup in it is barely supersaturated or if the sirup becomes more dilute during the storage because of absorbing water from a damp atmosphere, there is always danger of both the alkalinity and polarization becoming less. Juices which have been treated with sulphurous acid, other things being equal, yield more stable sugars than those which have not been, for, in the former, a small amount of sulphurous acid is retained which acts as an antiseptic.

The **form and sharpness of the crystals** depends not alone upon the amount but upon the nature of the non-sugars. Juices which have been well treated with lime always give better and harder crystals than those which have been merely superficially defecated. With equal purity of juices the sugar obtained from fresh beets at the beginning of the campaign always has a better grain than that obtained towards the end of the season from stored beets.

Certain lime salts appear to have a particular action upon the crystallization, and especially those which collect in the juices when a molasses desugarizing process is used. The sugar obtained from such juices, and in particular the after-product, is likely to exhibit crystals of a pointed or needle shape.

The raw sugar, as it is discharged from the centrifugal machines, is warm and by no means homogeneous; it is first cooled off, sifted, and mixed before it is ready to be stored.

The transportation of the sugar horizontally or on a slight incline is best accomplished by means of properly constructed drag conveyors, for in this way the crystals are not injured as they may be by screw conveyors. Such carriers are almost universally employed under or at the centrifugals; they carry the sugar to the bucket elevators and the latter in turn bring it to the sieves.

For **sifting sugar,** drum- or shaking-sieves are employed. Almost any sort of a sieve may be used for a centrifugated sugar which is dry and is of high purity, while, on the other hand, the moist 88° product is so sticky that it presents more or less difficulty. For the latter sugars shaking- or drum-sieves are most suitable and are made of circular, bent wires, whose interspaces are kept open by means of brushes or prongs. Inasmuch as the stickiness of the sugar increases with cooling the sieves are arranged to keep the mass from rapid cooling by drafts of air. The size of the interspaces between the separate wires depends entirely upon the nature of the sugar which is to be sifted, but at all events it is not advisable to make them so close together that tiny scales and lumps cannot pass through.

It is necessary, therefore, to prevent as much as possible the formation of any of these lumps in the sugar. Besides the scales which are formed in the vacuum-pan, the prevention of which has been described already, it is possible to form lumps, which will not permit of centrifugation, both in the open mixers and in the arrangements for the transportation of the massecuite. Lumps result from the drying of moist sugar or massecuite on the upper surface; these subsequently fall off in smaller or larger pieces.

The crystals in these lumps, unlike those produced in the boiling apparatus, are not fused together, so they can be separated from one another by mashing for a long time with hot sirup, and are then suitable for centrifugation.

The sugar which has been centrifugaled well from carefully boiled massecuite, which has subsequently been worked up well in closed crystallizers, scarcely requires any sifting. Inasmuch, however, as the sifting also serves to thoroughly mix the sugar it should never be omitted.

The sifted sugar is either placed in bags or stored loose. Usually the product has *cooled* sufficiently, in its passage through carriers and sieves, unless the massecuite is centrifugated very hot, so that it is ready to be stored. Under no circumstances should sugar be stored in a warm condition, and particularly not in heaps, for in such cases it may heat up still further; when this takes place dark sugar is found at those parts which are hottest and the alkalinity is greatly diminished, while in some cases it contains invert-sugar. This phenomenon is an oxidation and is brought about by the presence of certain organic non-sugars. When sugar on leaving the sieves is still warm it must be allowed to cool in small heaps and afterwards placed in bags or stored loose.

When the sugar is **bagged** the weight of the stored sugar is accurately determined; in the case of sugar stored loose the barrows in which it is transported are counted and weighed. Usually this process is not done with sufficient supervision, so that as a result the weight of the sugar that is stored rarely agrees with the weight which is finally sent away. The determination of the amount of sugar from the size of the heaps never gives accurate results, for the amount of space occupied by a given weight of sugar depends upon the size of the grain and the nature of the raw sugar, while, finally, the height of the different heaps varies greatly.

In order to save labor the **storage-room** is placed high up and the sugar is carried up in wheelbarrows on elevators, or by means of bucket conveyors. When the sugar is stored loose it is simply

dumped out from the barrows on the floor, or it falls from suitably arranged shoots; when it is bagged it is also easier to fill them from above.

Too great pressure upon the walls should be avoided in every case. If the sugar is heaped up high the walls must be very strong and well supported. When the sugar is in bags these should not be placed against the walls, and the bags should be laid alternately lengthwise and then crosswise, so that the pile is stable, and there is no danger of the bags sliding when they are being shipped.

Sugar stored in bags always keeps better than in heaps. Generally, the keeping quality of sugar depends on how free the sirup is from infection by molds. All conditions which favor this infection and the growth of molds act to injure the keeping qualities of the sugar. It is exceptional to find molds in sugars alkaline to phenolphthalein which is characteristic of those of proper and intelligent manufacture. The alkalinity alone is not, however, a protection against destructive changes in sugar. Cool and equable temperature, as little moisture as possible in the sugar, and a high concentration of the sirup adhering to the crystals are all hostile to the growth of molds.

The storeroom should be cool and dry. As far as possible warm places, or those into which the hot and moist air from the factory penetrates, should not be chosen for storing sugar. In the former case the sugar dries and besides losing in weight it becomes less suitable for refining, because the sirup in the crystals is then more viscid. In moist places, on the other hand, the sugar attracts moisture and easily becomes so moist that the sirup runs off from the crystals, the micro-organisms develop in it and cause the inversion of some of the sugar. The sirup may later run through the sacks or from sirup-stripes in the heaps. When the storage-place is cool and dry there is never any separation of sirup from the crystals if the sugar has been properly purged, even when it is only of 88° quality, for the sirup adhering to the crystals at the low temperature is so viscous on account of its supersaturation that it adheres as a film on the crystals.

CHAPTER XIX.

THE PREPARATION OF SUGAR CRYSTALS.

MANY factories, instead of stopping with the preparation of the raw sugar, manufacture a product which can be directly utilized, and they accomplish this by removing all the sirup from the crystals. In this way a crystallized sugar (granulated) is obtained, or powdered sugar, or sugar loaves (Pilée) but these products are not to be regarded in any respect as refined sugar, although perfectly suitable for many purposes. Refining is brought about by a dissolving and purifying process.

The preparation of sugar crystals from the massecuite is accomplished in the first place exactly as in the case of raw sugar, but as much of the sirup is removed as possible by centrifugation; to accomplish this the massecuite is not allowed to cool very much. The sirup that is not removed in this way is washed out by means of water, steam, or saturated sugar-solution, and in such a way that as little sugar is dissolved as possible. In order to improve the color a little ultramarine is added in the vacuum-pan and also to the wash-liquids. The ultramarine used should be of a good quality and carefully prepared, otherwise the sugar will be of a bad color.

Only good juices can be used to advantage for the manufacture of this grade of sugar. When the ordinary sirups are not pure enough they are often improved in quality by the introduction of a little of the after-product sugar. Naturally more weight is laid upon the production of a uniform grain and a careful working

up of the massecuite than when simply a raw sugar is to be made; it is not possible to prepare good sugar-crystals in this way from a massecuite which does not act well in the centrifugal machines.

For the manufacture of the sugar-crystals centrifugals of large diameter are suitable, although it is advisable to fill them to a less extent than in the former case, so that the layer of sugar resting against the strainer is less thick and can be washed more uniformly.

When saturated pure sugar-solutions are used as **clearing sirups** for removing sirup from the crystals while they are in the centrifugals none of the latter will dissolve, and all of the crystallized sugar will be converted into the desired product. But since a part of the product must be used in the preparation of the wash-liquid, or clarifier, and when once used it becomes so contaminated with sirup that it cannot be used over again for clearing, it is evident that the actual yield of sugar is considerably diminished.

In the beet-sugar factories pure sugar-solutions are seldom used as clarifiers, but usually the crystals are treated with **water or steam,** and frequently both are used together. In this case, also, it is necessary to use the water or steam in such a way that as little as possible of the sugar is dissolved out during the process. The water is introduced in as finely divided a condition as possible by means of a rose, or, still better, it is sprayed in by compressed air. The condensed water is removed from the steam before introducing it into the drum, or it is superheated, and the upper opening of the centrifugal is closed by a cover, so that there is no condensation by the steam coming in contact with the outside air. In all cases the water or steam will, despite all precautions, dissolve away a little of the sugar from the crystals, or else it will not remove all of the sirup. After or during the washing of the crystals with water, steam is often introduced, and in this case it is well to make use of the so-called *Russian steam-mantle,* in which case the steam is introduced between the mantle and the drum. The chief action of the steam is then to warm up the contents of the drum, and without the condensation of any considerable amount of water upon the sugar. The Russian steam-mantle is, as already mentioned, also used to advantage in the preparation

of raw sugar or the after-products, because it prevents the sirup from becoming too viscous in consequence of too great a cooling. The steam should not be directed against the drum, because in such cases those parts of the drum which the steam or water strikes against suffer in the course of time. Consequently the steam is directed against a sheet of metal which serves to turn the direction of the vapor to one side and distributes it uniformly throughout the apparatus.

Frequently, before washing the crystals with water or steam, they are covered with the so-called **covering-sirup,** the latter being made up of the liquid thrown off by the centrifugals in the last washing of the previous lot of crystals, or of sirup which has been evaporated to the saturation point. By means of these liquids first of all the green sirup is displaced; the lighter sirup or thick juice then adheres to the crystals, and either of these latter can be removed with materially less steam or water. When this method of preliminary covering is used the process becomes somewhat more involved, and it is a matter for calculation to determine whether the increased sugar-yield compensates for the extra trouble. The advantages to be gained, even when these preliminary covers are particularly clear and pure, are at all events not very great. Since some sugar will be dissolved from the crystals in every case when pure, white crystals are to be obtained, the chief requirement for a good yield is the careful **separation of the sirup purgings, according to their purity,** so that the better portions can be again boiled down with the thick juice for the production of sugar-crystals. The first portion of sirup centrifugaled is the so-called "*green sirup,*" which in the ordinary method is collected by itself, sometimes being thinned by steam. The sirup that is next obtained in the covering process is at first carried off in the green-sirup gutter, but as soon as it becomes lighter colored, showing covering-sirup, it is run into a different gutter and either carried back directly to the thick sirup, or it is added by itself to the vacuum-pans during the boiling process.

For the separation of the covering-sirup according to its purity there are a number of different devices in use. It is important

for the simpler forms, in which the separation takes place outside the centrifugal machines, that the centrifugation of each filling should not be accomplished in too short a time, so that one grade of sirup will run off sufficiently before a second quality is thrown off, the green sirup being removed when the covering process begins and, conversely, the better covering-sirup run off when the centrifugals are filled with fresh massecuite. In the case of large centrifugal machines which must run for a longer time the separation of the sirup is better than in the smaller ones. In other methods of separation the sirups of different degrees of purity are separated in the casing of the centrifugal apparatus itself, so that here the separation is a sharp one, to the extent that it is possible to remove the sirup by centrifugation. In this way the centrifugal work is accelerated. Even here, however, more centrifugals are required in the manufacture of the sugar-crystals than when merely the raw sugar is produced.

The **further treatment of washed sugar-crystals** depends upon the product which it is desired to manufacture. Granulated and crystal-sugar must leave the centrifugals in a warm and somewhat moist condition, so that the crystals do not bake together to form solid pieces, whereas, in the manufacture of the Pilée (loaf) sugar this cementing is desirable. When the crystals have been prepared by washing with steam it is not necessary to have any particular arrangement for drying them, for this is sufficiently accomplished during the transportation and sifting of the product. In case the crystals have been washed with water they must be dried in drums or granulators. When a product of uniform grain is desired it must be sifted. The smaller crystals, or sometimes the whole product, are frequently powdered. It is important that even these sugar-crystals, as in the case of the raw sugar, must be thoroughly cooled before they are sacked or stored, as otherwise the sugar is apt to get a yellow coloration. In the preparation of Pilée, centrifugals of an especial design are employed which provide for the easy removal of the hard loaves.

Another method for preparing white crystals from the massecuite is the **massecuite wash.** The massecuite, being brought

to the proper point in the vacuum-pans, is cooled to 40° or 50° (104–122° F.) in the crystallizers, and, finally, diluted till the mother-sirup is only slightly supersaturated. Under no circumstances should there be fine crystals or crystalline meal, but a uniformly good grain should be obtained. The massecuite is placed in large rectangular or oval tanks provided with sieves at the bottom, and the sirup draining off is sucked away by means of a pump. As soon as the first sirup has been drained off as completely as possible, one that is purer is poured over the mass and this is likewise drained off, the operation being repeated three or four times with sirups of constantly increasing purity. The sirups first used come from the previous coverings, but in the last case a pure sugar-solution is used; either such a solution is prepared or else pure water is added, which dissolves enough sugar from the crystals to become saturated.

Particular stress must be laid upon the importance of separating the sirup well after each covering. The first sirup has a purity of 70 to 75. This is taken out of the process and no longer used for washing. The second sirup serves for the first cover of the next massecuite and so on. The sirup is run into cells or into ordinary tanks, in which the supersaturated sirup that has drained off at the beginning can be diluted to the proper concentration with water.

Since the temperature in the wash-room is quite different at different seasons of the year it is not possible to prescribe once for all time any definite *density for wash-sirups*, but this density must be governed by the prevailing temperature, so that the sirups used will be saturated with sugar in all cases, and not supersaturated at one time and undersaturated at another. The temperature in the wash-room should not fall below 20° C. (68° F.), because at temperatures lower than this the viscosity of the sirup increases very considerably and the washing will then require a much greater length of time; it is advisable that the room should be heated in winter. In the same sense any supersaturation of the wash-sirups acts detrimentally, whereas, on the other hand, although undersaturated juices effect a much more rapid washing they dissolve sugar, and, consequently, lessen the yield. Only when

the massecuite contains a strongly supersaturated sirup is it desirable to use for the first cover an undersaturated wash which will become a saturated liquid when mixed with the supersaturated sirup, thus accelerating the washing without dissolving any sugar from the mass. It is naturally preferable to work up the massecuites in the crystallizers so that the mother-sirup will form simply a saturated solution.

The yield of white crystals is greater by this method than when centrifugation is employed, because a green sirup of lower purity is in each case removed from the process. This result, however, is obtained only after the expenditure of considerable time.

A further disadvantage of the washing method: If a sirup is used for a relatively great length of time before it is thrown out there is a possibility of its changing. At all events it is necessary to exercise the greatest care to avoid all causes for inversion of the sugar. Great cleanliness is required above all things, and sirups should also show the desired amount of alkalinity. This alkalinity is maintained by the addition of soda rather than lime. When inversion of sugar sets in to any extent the only remedy is to carefully clean all tanks and cells and start the work afresh.

If the sugar obtained by washing is to be worked up into crystals it must be centrifugated and then dried. Usually this washing process is only for the purpose of obtaining crystals that are suitable for refining; in such cases the crystals are dissolved directly in the tanks.

CHAPTER XX.

WORKING UP CENTRIFUGAL SIRUP INTO AFTER-PRODUCTS.

The main object in working up centrifugal sirup from the first products is to obtain all the sugar possible in crystal form, but not with too fine a grain, so that the mother-liquor eventually obtained is a true molasses.

This end is attained in different ways: first of all the sirup must be thickened or boiled down. For this purpose a **vacuum-pan** is used which is of the same construction as that used for boiling the concentrated juice; one heated by means of pipes, arranged vertically or inclined and of large diameter, being preferred. For the thickening of the sirup and the management of the apparatus the same directions and rules hold that were given for boiling juice, except in so far as they were applicable only to juices of high purity. It is particularly important to make sure of good sirup circulation, that the sirup is well warmed, enters in the lower part of the apparatus, and that the heating is by means of low-pressure steam.

There are three principal processes for **working up centrifugal sirup.**

1. Blank boiling of the sirup, subsequently allowing the sugar to crystallize out in tanks, with or without the addition of exciting crystals.

2. Blank boiling of the sirup and working up the massecuite in crystallizers, in which the crystals are either formed by cooling or ready formed crystals are added.

3. Boiling the sirup to grain, or with the addition of exciting crystals, and further working up of the massecuite in crystallizers.

By all of these methods of working the complete crystallization of the sugar up to the formation of true molasses can be effected, but the length of time required is different. It is assumed, of course, that in each case the process is correctly carried out.

In the proper working up of centrifugal sirup the correct concentration and temperature should be maintained during the whole period of crystallization, and those conditions established which are favorable for crystallization. Exactly as in the preparation and treatment of the massecuite of the firsts here, again, in working the massecuite from the sirup a definite supersaturation is most favorable, but this depends upon the purity and the temperature. Too great supersaturation, especially in the case of pure sirups, tends to form new and fine crystals at the time when it is not desirable that any more crystals should form, and so tends to retard or prevent the desired crystallization, and particularly at low temperatures, on account of the greater viscosity of the sirup Too low supersaturation, on the other hand, makes crystallization take place much more slowly, especially in the case of impure sirups.

Only when centrifugal sirup is boiled to grain, or with exciting crystals, can the concentration be constantly maintained at the supersaturation-coefficient which is known to be the most favorable. In the case of all the other methods of working the process should be conducted so that the mother-liquor remains supersaturated up to the last, that is, until all the crystallizable sugar has separated out. Such a massecuite will consist of sugar-crystals and an actual molasses in a saturated or slightly supersaturated condition.

The supersaturation ratios of impure centrifugal sirups are not as simple as in the case of the pure sirups. Whereas, in the latter, the coefficient may be assumed to be practically the same as in the case of pure sugar-solutions and the extent of supersaturation can be readily computed by means of solubility values of pure saturated sugar-solutions; **in the case of sirups the supersaturation relations depend upon the amount and nature of the non-sugars present.**

Small amounts of but one non-sugar in solution with sugar

lessen the solubility of the latter, while larger amounts increase the solubility. As a rule, non-sugars which take up water of crystallization diminish the solubility of sugar. Those which tend to increase the solubility of sugar most are alkaline salts of organic acids. Practically the same phenomena are observed in mixtures of non-sugars, in general, such behave as the sum of the equivalents of the individual constituents, not as the sum of the individual influences of the constituents.

It appears however, as if the total non-sugars, in the sirups and molasses from beet-sugar manufacture, in spite of great variation in quantity, characteristics and composition always have practically the same influence upon the solubility of the sugar, as long as the proportion of ash to organic non-sugar remains practically the same, and no abnormal constituents are present. In pure sirups there is never any variation in this solubility influence; when it does appear it is first noticeable in molasses liquors. Hence it is almost a certainty that sirups of more than 65 purity, even of different crops, will show practically identical sugar solubility.

Among the substances having strong influence on the solubility of sugar, especially in molasses, are raffinose, organic lime salts, particularly those formed from the decomposition of invert sugar by lime, likewise invert sugar itself. All these substances, whether free or combined in salts induce sugar crystallization, in other words, lessen its solubility.

In order to prevent any misunderstanding it is important to emphasize in this connection that these solubility relations have in themselves nothing to do with the formation of molasses, as is frequently erroneously assumed. The solubility data simply show how much the sirup must be evaporated in order to bring it to the crystallizing point. If the sugar is more soluble in one non-sugar than in another it is evident that the former must be evaporated to a greater extent before the sugar will crystallize; this is assuming that the liquid is purer than a true molasses, for the latter can be evaporated to dryness without any sugar crystallizing out.

The solubility of sugar varies with the temperature and the proportion of water to sugar in impure, saturated sugar solutions is quite different than in pure. The reason for this is that in the strong concentrating of solutions at high temperature, not only the sugar-content but the non-sugar-content increases and consequently the latter exerts greater solvent action on the sugar.

For example, a sirup of 62 purity is saturated at 20° (68° F.) when it contains for each part of water 1.15 times as much sugar dissolved in it as a pure sugar-solution saturated at the same temperature, that is to say, 2.04×1.15 parts of sugar. Then the composition of this sirup is: 20.9 per cent. water, 49.0 per cent. sugar, 30.1 per cent. non-sugar. But this same sirup is saturated at 70° (158° F.) when it contains 1.5 times as much sugar as a pure sugar-solution saturated at 70°, hence, with 1.5×3.2 parts of sugar, its composition is: 11.4 per cent water, 54.9 per cent. sugar, 33.7 per cent. non-sugar. Accordingly in the sirup saturated with sugar at 20° there are 1.44 parts of non-sugar per part of water, while in that saturated at 70° there are 2.96 parts dissolved. This doubling of the strength of the non-sugar solution accounts for the increased solubility of the sugar.

Temperature by itself seems to have no influence on the solubility influence of the non-sugar, at least only an indirect one, as when temperature variation causes a change in the amount of water of crystallization combined with the salts in solution with consequent alteration of the amount of free water present.

The value expressing the excess of sugar dissolved in a sirup per unit weight of water over that in a saturated solution of pure sugar, at the same temperature is of great practical significance in understanding and controlling after-products. This figure is known as the "**saturation coefficient.**" It follows along this reasoning that the saturation coefficient for all sirups is smaller the lower the temperature and greater the lower the purity, these changes always being results of concentration variations in the non-sugars in solution.

Consequently, the ratio of sugar in a unit weight of water in the mother liquors to that in a pure sugar-solution at the same tem-

perature is recommended as the best control figure for working up after-products in a practical way. Since both methods are founded on the same principles it is a matter of preference which will be used. The saturation coefficient seems to be simpler and explain crystal formation better, moreover the supersaturation can always be expressed through the former as a proportion.

The values of saturation-coefficients of sirups of different purity at different temperatures, in other words, the extent of the influence of non-sugar solutions of different concentrations on the sugar solubility, are not very well known. Investigations are rather difficult to make. The results also vary according to whether the saturation is determined by crystallizing out from a supersaturated solution or dissolve the sugar in a solution which is unsaturated. In the first case the saturation coefficient is larger than in the latter and this difference is greater the lower the purity of the sirup.

For practical work, the coefficients found by crystallizing sugar out from supersaturated solutions are the correct ones. From the few experiments which have been made only approximate values can be given, but these are, however, sufficient for practical purposes.

First of all it is of interest to show the saturation relations in centrifugal sirups of different degrees of purity at the final temperatures of the crystallization, which lie betewen 40° and 50° C. (104–122° F.) At these temperatures the saturation-coefficient is

In saturated sirups of	75	purity about	1.0
" " " "	75–70	" "	1.0 –1.05
" " " "	70–65	" "	1.05–1.10
" " " "	65–60	" "	1.10–1.25
" " " under	60	" "	1.3

The saturation conditions in a centrifugal sirup of about 60–62 purity, that is in one which is practically a molasses, is for different temperatures approximately as follows:

Temperature.	In One Part of Water are Dissolved			Saturation coefficient of Sirup.
	In a Saturated Sirup of 60–62 Purity.	In a Saturated Solution of Pure Sugar.	Difference.	
80° C. (176° F.)	5.8	3.6	2.2	1.6
70° " (158° ")	4.8	3.2	1.6	1.5
60° " (140° ")	4.1	2.9	1.2	1.4
50° " (122° ")	3.4	2.6	0.8	1.3
35° " (95° ")	2.8	2.3	0.5	1.2
20° " (68° ")	2.3	2.0	0.3	1.15

By means of these data the composition, or at least the water-content of the molasses-mother liquors can be calculated, assuming crystallization to be properly carried out and the purity of the molasses about 60. Such molasses cannot dissolve sugar because it is saturated, while, on the other hand it will be the least hindrance to crystallization, since its viscosity is the smallest possible. Obviously in practice the molasses-mother-liquor must be kept somewhat supersaturated, in order that crystallization will go on till the end, and as a fact the supersaturation-coefficient is kept at from 1.05–1.10. The following data of the composition of molasses-mother-liquors at different temperatures at completion of crystallization give the highest water-content permissible, but which actually in practice ought not be any less.

COMPOSITION OF MOLASSES.

At a Temperature on Completing Crystallization of	Sucrose.	Water.	Non-sugars.	Purity.
35° C.(95° F.)	49.4	17.6	33.0	60
50° " (122° ")	51.0	15.0	34.0	60
60° " (140° ")	52.4	12.7	34.9	60
70° " (158° ")	53.3	11.1	35.6	60

Moreover, from these data the proper concentration can be calculated for the final thickening of a sirup, which is boiled blank, so that the final molasses will have suitable supersaturation. All that is necessary is to make a calculation of the sugar required to be dissolved in the molasses to bring it to

the purity of the sirup and then reckon the result as a percentage. When sirups are boiled to grain the supersaturation-coefficients which are maintained during boiling usually depend on other circumstances, which will be explained later. The normal molasses data only serve in such cases to establish the proper concentration for purging.

If the proper concentrations of sirup and mother-liquor sirup are used all the conditions necessary for best crystallization are fulfilled, since the sirup under such conditions has the least viscosity.

The **viscosity of sirups** or molasses is decidedly a hindrance to rapid graining, since the molecules of dissolved sugar must overcome the resistance caused by this viscosity in order to come in contact with the crystals. This resistance cannot be appreciably lessened by mechanical movement of the mass, because the sirup particles adhering to the crystals, and out of which the sugar must crystallize, do not in the least change their position relative to the crystals. Mechanical movement of massecuite is of no use whatsoever, except to equalize temperature and concentration in different parts of the apparatus, while the maintenance of uniform concentration around the crystallization centres depends on diffusion, which in turn is dependent on the viscosity. To obtain the most appropriate concentration of the sirup there must be for the given conditions the least possible supersaturation, as this gives the least viscosity, for this latter increases very rapidly with the *degree of supersaturation*. *Temperature* has still greater influence on viscosity. At temperatures of from 75°–90° C. (167°–194° F.), that is at the ordinary boiling temperatures of the vacuum-pan, the viscosity of sirups, whether of high or low purity, or whether saturated or quite strongly supersaturated, is practically the same. If, however, the temperature falls to 60°–65° C. (140°–150° F.) the viscosity increases much more in proportion as the sirup is impure or supersaturated; indeed, the viscosity of impure sirups can be so great at ordinary temperatures that no crystallization at all can occur. On the other hand, centrifugal sirups can be supersaturated to a greater extent the higher the

temperature, and the crystallization period be correspondingly shortened. A good high temperature can only be maintained for any length of time in vacuum-pans or crystallizers, hence, as experience has shown, crystallization in such apparatus is decidedly quicker than working with wagons or tanks.

Other necessary conditions for good and quick crystallization of centrifugal sirup are **uniformity of temperature and concentration** in all parts of the massecuite and a **suitable amount of crystal foundation.** Uniformity of temperature and concentration can only be maintained in vacuum-pans or crystallizers. Moreover, such apparatus have the advantage that the crystal foundation which is put into the massecuite or formed from it always remains uniformly distributed throughout, and is therefore best utilized for crystal nuclei. The greater the number of such nuclei the smaller the crystals, and for an equal weight the quicker the removal of the sugar from the sirup. For the manufacture of fine-grained sugars there is, however, in practice, a certain well-defined limit as to size, for necessarily the crystals must be sufficiently formed at least to give no difficulty in purging or cause loss. Obviously, too, the market requirements, or the use to which the sugar is to be put, will be an important consideration in the choice of grain, so that it often is profitable to add a decidedly coarse grain, of which a much greater weight will have to be used to desugarize the sirup well.

Working up after-product sirups is often the bugbear of the establishment, particularly in beet-sugar factories; but if the necessary care and supervision are spent on this work, better yield and quicker crystallization can surely be obtained with no greater cost whatever, and these are certainly important improvements. The conditions bearing on this work have, therefore, been described more in detail than would otherwise be necessary.

Control in working up after-products is much facilitated by use of apparatus showing continuously the concentration of the sirup during boiling in the vacuum-pan. Formerly the thickening was controlled by the string-proof, which gave fairly reliable indications when made by a skillful and reliable sugar-boiler. In many estab-

lishments the sirup after being boiled blank was tested by a spindle. When this spindle-test was made on the hot sirup it was unreliable at the high density; when the test was made in the laboratory the results were obtained too late to be availed of in making any change in the concentration. An accurate determination of the concentration of the massecuite actually in the vacuum-pan is the only one of use, and this can only be made by the boiling-control apparatus already described, using tables and temperatures adapted for sirup.

(*a*) **Working up Centrifugal Sirup in Tanks or Wagons.**—It is impossible by one blank boiling of a centrifugal sirup, having the usual purity of about 75, to obtain complete crystallization of sugar, for the sirup would have to be made much too thick. On this account, where complete sugar-extraction is desired, the wagon- or tank-process is generally used, the sirup being boiled twice, the first time not too stiff, so as to get a good grain and a molasses of from 65–68 purity, the second time to a concentration suitable for this purity.

No hard-and-fast rules can be given for the boiling of firsts, because the density is dependent on the size of grain desired in the second product as well as the size of the tanks and the temperature of the crystallizing-room. Ordinarily the sirup is cooked to a water-content of 13 per cent. and is put into rather small and shallow tanks. When working with the very pure sirups from refined sugar the massecuite of the second products is also run into tank-wagons.

It is only a question of time when such working up of centrifugal sirups from first products will disappear from all factories and be replaced by use of vacuum-pans and crystallizers, for at least as good results as obtained by the tank-process for second products can be got with the poorest boiling-apparatus and time and labor saved besides. At least, with poor apparatus the purity of the molasses is rarely under 65, so that it is necessary to boil again to a third massecuite, which must be crystallized out in large tanks

or pits. Indeed, if the purity of this second product is only about 3 per cent. higher than the final molasses reboiling can be done to advantage, for a lowering of the purity one unit will increase the yield of final product about 1.7 per cent. of the massecuite.

Boiling such impure sirups should be done with the aid of the boiling-control apparatus, using the following table calculated for a molasses of 58 purity.

True purity of centrifugal sirup	68	67	66	65	64	63	62	61	60
Water-content of sirup after boiling, per cent.	11.5	11.8	12.2	12.5	12.8	13.2	13.5	13.8	14.1

These **values for the water-content** of thickened centrifugal sirups, it should be observed, are the highest permissible for obtaining complete crystallization of after-product massecuites. As a rule it is advisable to thicken a little more to be on the safe side, and make the water-content ½ to 1 per cent. less than given in the table. This is also advisable for another reason: If the massecuite is too fluid during separation of the crystals in the tank they sink to the bottom while still very small, and so deprive the upper layers of the necessary crystal foundation. On this account a certain viscosity is unquestionably necessary, and hence to obtain this the water-content must be made lower in proportion to the time a high temperature is maintained in the tanks. Evidently boiling should be somewhat stiffer for large tanks than for small ones. Moreover, if the steaming-out liquors are not kept separate, but go into the tanks mixed with the strike, obviously the thickening must be greater in order to give the prescribed density to the sirup actually in the tanks.

The **initial temperature of the massecuite** is the temperature at time of discharging the strike, say 80°–90° C. (176°–194° F.). In order not to cool too quickly the room should always be heated to a temperature of about 40° C. (104° F.). This heating is done by means of steam or heat from special coke-furnaces. In two months at the most the temperature should have sunk to 30° C. (86° F.), and the crystallization finished. The best-formed crystals, the size of which depends on luck, for even the most skillful sugar-boiler

cannot succeed in getting massecuites which crystallize uniformly, will have in the main sunk to the bottom, leaving the supernatant sirup practically free from grain. The massecuite can be removed without trouble and purging is easy. It is a very good idea to pump the massecuite into crystallizers by means of a massecuite pump, if the former are available, and stir and heat up to 40°–45° C. (104°–113° F.), or heat to the required temperature in tubular heaters before purging. In either case purging can be done with little or no addition of dilute molasses, so that any solution of crystals is avoided.

Massecuites boiled too stiff, and consequently improperly, must be worked up in the mixer with dilute hot molasses. This always dissolves much sugar, so that the purity of the final molasses is often 2–3 per cent. higher than that from a massecuite properly boiled and handled.

Tank crystallization is always unsatisfactory, because the crystal foundation soon becomes wanting, as the crystals in the upper layers on account of their weight soon begin to settle, and, consequently, the upper layers of sirup in the tank always have a higher purity than those below, in which the crystals have deposited. In order to mitigate this evil, stirrers, either horizontal or vertical, have been recommended to mix the contents of the tanks, as well as pumps for lifting the lower layers and distributing them over the surface, so as to make the crystals settle through the sirup which is less exhausted. The cost of such machinery is, however, disproportionally great.

Stirring blank-boiled massecuites in the tanks is done apparently most simply and cheaply by air bubbles, although this method to be practical requires expensive apparatus and suitable supervision. This **stirring by compressed air** is only successful with massecuites of a purity not higher than 72–73. If the strike is of higher purity, it must be allowed to crystallize and desugarize some or be boiled to grain before stirring. The tank is so constructed that the compressed air enters at the very bottom, through masonry troughs in the floor for instance. The air should enter in a rush in puffs, being under high pressure, either through

a movable pipe or a hose connected with the air line or through a multiple pipe system in the tank. It is a good idea if these pipes have a slit underneath so that the compressed air blows out sideways and so stirs the massecuite better. The time of tank crystallization apparently can be shortened to some extent, and a somewhat better yield obtained by adding to the boiled sirup a relatively small amount of *fine sugar crystals*, sugar-meal, or powdered sugar, about 0.1 per cent. or less, according to its fineness. These crystals or crystal fragments serve as a foundation or excitant for starting crystallization immediately, and at least that time is saved which would have been necessary for forming the initial crystal nuclei. It is best to boil the sirup a little stiffer for this manner of working, so that the crystals will remain as long as possible in suspension in the hot massecuite and not quickly settle to the bottom. As a rule, the sugar made in this way is of fine grain, purges poorly and gives a poor yield.

That tank-work, in so many ways so disadvantageous for crystallization, gives relatively good results, is due to the fact that the time of graining can be extended to any length. Its disadvantages are, that the work is dirty, expensive, and to a certain extent unhealthful. These evils are the chief reasons for its abolishment.

(*b*) **Working up Centrifugal Sirup in Crystallizers.**—By this mode of working, also, the centrifugated sirups of the first products are usually not desugarized to a purity of final molasses at *one* operation, as the concentration of the sirup boiled blank would always be too high. For complete exhaustion by crystallization, centrifugal sirups should be thickened and boiled as indicated by the tables giving data for tank-work. In the case of the purer sirups, which must be as much supersaturated as possible, far too many crystals would be formed if crystals were added, on account of the small crystal nuclei being already present.

To prevent this, the purer centrifugal sirups, over 70 quotient, should be boiled thinner than the table shows; then, however, they cannot ever be reduced to the purity of final molasses. As a matter of fact, a final sirup is obtained which has a purity

varying, according to the sirup boiled, between 63 and 65 or higher, so that such sirup can be boiled again to advantage and worked up in tanks or crystallizers.

While it is true that purer sirups can be mixed with impure sirups, or molasses, and brought to a purity of 70–72, and that such mixtures can easily be boiled and brought down to a molasses purity, the crystallization is injured by such methods and the greatly increased volume of the massecuite requires more crystallizer capacity and more labor for purging.

Ordinarily, centrifugal sirups are boiled for crystallizer work to a water-content of about 10 per cent. and crystals are allowed to form by cooling in the crystallizer, or 15–20 per cent. of sugar is added as a foundation. The sugar added should always be first warmed and mixed with hot, thick sirup, as addition of cold sugar might form second grain. It is much better to draw the sugar slowly into the vacuum-pan after the sirup has become suitably concentrated, either directly or mixed with sirup.

Another method of boiling consists in thickening the sirup, which should not have a purity greater than 72, at the high temperature of 95–100° (203–212° F.) to a water-content of 7–9 per cent. and then induce crystallization by shaking violently by means of steam injection. A comparatively large quantity of fine crystals are formed by this action, which accelerates graining, and providing they attain sufficient size, do not clog the centrifugals.

Cooling-off in crystallizers must take place very slowly. Such apparatus should be equipped with a water-jacket, so that the massecuite can be warmed when necessary. The final temperature should not be too low, usually not lower than 40° (104° F.). At times hot or cold air is passed over the massecuite, which regulates the cooling, and at the same time causes evaporation and a further concentration.

Massecuite in crystallizers only needs to be stirred very slowly, at most, the stirrer should make from one to two revolutions per minute, and may even be discontinued for certain periods. When warming or cooling, obviously the stirrer must be constantly in motion.

The **stirring period** depends on the extent the sugar is to be extracted, and upon the purity of the resulting sirup. Two to three days are sufficient to reduce a sirup of 75 purity to one of 65 purity. Five to six days at least are necessary to reduce a sirup of 65–70 purity to about 60 purity. It is no more possible by this process than by tank-work to reduce sirups of higher purity than 70 in a single boiling to the purity of true molasses. Moreover, the impure sirups never crystallize uniformly; often the purity of the centrifugated molasses shows large variation, and the purging itself is frequently very difficult.

When crystallization is complete, the massecuite should usually be thinned to a more or less degree so as to make it purge easily. Cooling on the way to the centrifugals must be avoided.

If **sugar is added for grain foundation,** raw first sugars should be used to get good, large crystals. Usually, however, fine-grained after-product sugar is used, or a part of the massecuite of the previous crystallizer is put in. Working thus simplifies the process, it is true, but second grain is always formed in with the large crystals, while the latter tend to form in plates, which are not so much desired and are apt to purge badly. Broken crystals are recommended for rapid crystallization. Crystal fragments and splinters remove sugar from solution with great energy and grow into normal crystals, after which they behave like any other crystal.

(*c*) **Boiling Centrifugal Sirups to Grain.**—The difficulty encountered in completely desugarizing sirups of high purity in crystallizers can be overcome by boiling such sirups in the vacuum-pan, either to grain or with grain previously added. If centrifugal sirups are grained, or grain added to the weakly supersaturated sirup, sufficient sugar can be crystallized out by one proper boiling in a vacuum-pan to reduce the purity of the sirup to at least 65–67.

With no fear of trouble, the concentration of such impure sirup can be made so high that any further crystallization, up to complete desugarizing of the molasses, can be accomplished either by reboiling in the vacuum-pan itself, at the pan temperature, or in crystallizers by gradual cooling. In boiling centrifugal sirups to

grain, just as in boiling juice-sirups, the pan must be regulated so that the mother-sirup **is kept continually at the proper degree of supersaturation during evaporation,** and not obtained by gradual cooling, as in regular crystallizer work, where crystallization must perforce take place at a lower temperature, not so favorable for the purer sirups.

There are many different and conflicting ideas about boiling sirups to grain. Those methods emphasizing details of minor importance as far as the actual conditions affecting crystallization are concerned, such as, for example, the kind of mechanical stirrer to use or the arrangement of the sirup feed-pipe, obviously will not lead to results of permanent value. The only satisfactory boiling method is one which keeps the sirup, at every stage of the process, at a concentration most favorable for crystallization, and in which, by the aid of suitable circulating devices, the temperature is continually uniform throughout, and gives a boiling-point actually corresponding to the vacuum.

Whereas, in boiling juice-sirups to grain, maintenance of proper concentration, according to external appearances, can be learned after some practice, and mistakes made here might be corrected in working up after-products, in the case of centrifugal sirups unexpected difficulties are met owing to their great viscosity, which is affected by temperature. Final boiling of centrifugal sirups, however, has to be done practically perfectly, to avoid large losses in the sugar-yield. In this work the *boiling-control apparatus* is again of service, since the boiling must be slow, and therefore the indications of the simplest form of apparatus can be followed without trouble; such apparatus is quite necessary for the boiling to grain, and should show the water-content of the sirup.

The concentration of the sirup, or mother-liquor, that is, its water-content, must be calculated for every boiling, especially for the various pure sirups. In these calculations, too, the supersaturation-coefficients are the fundamental data.

While graining, the coefficient for the better grade centrifugal sirups should be the same as for juice-sirups, but be taken somewhat greater when the purity falls as low as 68.

After grain has been formed, the coefficient, just after feeding with sirup, should be somewhat diminished; but as soon as the crystals become of perceptible size it should again be raised, but raised gradually, according as the crystals grow and the purity lowers. It is advisable to lower it again and when the pan is finished.

In actual practice, data of supersaturation-coefficients are not of use by themselves, but the water-content of sirups of various purities and at different times should be calculated by means of such tables; for, with help of such data and by use of the control-apparatus, the sugar-boiler can finally make the boiling a purely mechanical process.

Grain can be made from centrifugal sirup, thickened according to the indications of such tables, or by the string-proof, or, as in the juice-sirups, by introduction of new liquor, or even solely by agitation caused by mechanical stirrers, this being simply what is known as crystallization in movement, and is regulated, according to the data of the tables, so that in a certain time the proper amount of crystals is formed at the prescribed concentration. Special skill is not necessary for making grain by this latter process; the pan-man must rather avoid allowing grain to form too long. In the purer sirups, of, say, 75 quotient or more, suitable grain is formed in a few minutes after the concentration is reached. In more impure sirups, $\frac{1}{4}$–$\frac{1}{2}$ an hour or more passes before the grain becomes visible. Obviously, graining can be expedited by using greater concentrations; but, if that is done, there are always too many crystals and the grain is too fine. As in the case of first product, it is important that the charging sirup is properly heated so that any sugar which has separated out in cooling after the centrifugal work or passed through the sieves will be redissolved. If this is neglected, there will be fine grain in the pan which will interfere with the regularity of the graining.

Diluting the sirup, which is sometimes recommended, is entirely unnecessary. It increases cost of evaporation and lengthens boiling. It is only needed when very large grains have been left in the sirup.

As soon as suitable grain is formed, sirup is again drawn in, and the steam in the coils, which was entirely shut off during forming of the grain, is again applied, and the heating and juice-feed so regulated that the water-content remains constantly at the value calculated for this particular strike. Boiling must go slower in proportion to the extent that crystallization is to be carried in the vacuum-pan. In 16–24 hours, ordinarily, a sirup purity of about 68 is reached, but for 62 the boiling must last 60–72 hours.

It does not appear advisable to carry this desugarizing of the mother-sirup in vacuum-pans to more than 65–68 purity. The massecuite, when boiled to about this point, is discharged into **crystallizers,** in which it is stirred for several days, while it is **gradually cooled** and a **regulated amount of water added.** Cooling is so regulated that the temperature sinks about 10° (18° F.) in 24 hours, experience having shown that crystallization of the sugar on a crystal foundation progresses most favorably under such conditions.

The supersaturation increases as the temperature falls, although sugar is continually crystallizing out. The reason is chiefly because the saturation-coefficient, as has been explained before, decreases with falling temperature. The supersaturation will, therefore, be so great that finally second grain will begin to form. In order to prevent this second grain forming in the crystallizers, since, being in the form of crystal flour, it cannot be removed by the centrifugals and makes the purging very bad, water is added at a prescribed temperature, the amount being proportioned according to the purity of the massecuite and the water-content of the mother-sirup at the time of discharging the pan.

For example, on the first day the temperature of the jacket of the free space of crystallizers should drop from 90° to 75° (194° F. to 167° F.) on the second day to 65° (149° F.), on the third, 55° (131° F.), on the fourth, 45° (113° F.). Water in calculated amount should be added for every 4–5° (7–9° F.) drop starting from 80° (176° F.) (condensed water of best quality being used). As a basis for this calculation, experience shows

that crystallization progresses best without formation of new grain at a supersaturation of 1.05–1.15. When the massecuite is properly boiled, for every temperature drop of 4–5°, 4 liters of water are added per cubic meter of crystallizer capacity (0.03 gallon per cubic foot) for 70 purity, 3.5 liters (0.026 gallon), for 75 purity, and 2 liters (0.015 gallon) for 80 purity. By this process, in the space of 4–5 days there will be a massecuite cooled to 35°–45° C. (95°–113° F.), which will be free from gumminess and purge easily, giving an after-product sugar of good grain and high purity, as well as a true molasses.

In order to arrive at these results with certainty it is advisable to make systematic tests of the mother liquor separated from the crystals at periods of two and four days' stirring, taking the apparent dry substance (Brix) according to the dilution method and the apparent purity. At the end of two days the water content should be 12 per cent., corresponding to 91° Brix, in a syrup of apparent purity, 62–64, and after four days, 15–16 per cent. water, corresponding to 88–89 Brix. It is worthy of special note that the apparent purity differs from the true the more the sirup or molasses is diluted for the Brix determination and the lower the ratio of ash to organic non-sugar. This difference is proportionally much greater as the purity lowers.

In boiling centrifugal sirups, **mechanical sugar losses,** such as foaming and entrainment, are more likely to occur than when boiling juice-sirups, because the former are more viscous and become superheated more readily, especially if there is trouble with the vacuum, but by some care, and having a suitable vapor-space, loss can always be avoided.

Losses from decomposition of sugar will take place in boiling and heating centrifugal sirups, as it does in every sugar-solution. It is, however, very small in alkaline sirups; and in the newer after-product processes it is less than in tank-work, because, as has been shown above, long-continued heat has a more injurious influence than a higher temperature maintained for a shorter time, providing that this does not exceed 90°–100° C. (194°–212° F.). There is a marked sugar decomposition in neutral or acid sirups, however.

The treatment of **after-product sugars** is therefore precisely the same as for the first, as far as this latter point is concerned.

In many factories, after-products, especially those which are fine-grained, of low yield, and practically unsalable, are redissolved in the thin juice. Sometimes these massecuites are boiled up and discharged into tanks with sieve bottoms and not centrifugated, the mother-sirup being drained off after crystallization, and the slimy sugar remaining behind melted up in the same tank. Since every boiling entails loss and expense, it is advisable to calculate for each individual lot whether there is any profit in working over for after-products. The general idea is that molasses sugars are better in proportion as the sirup is less completely desugarized, so that a product giving a molasses of 63 purity must be better than one giving 60 purity. This is erroneous. The quality of after-products depends principally, as does that of first-products, on the juice treatment and the graining. If these processes are carried out carelessly it certainly will be necessary to shorten the crystallization period to obtain massecuites which will purge well and avoid slimy sugars. With good crystallization the grains are well formed and the sugar granular and not slimy, and the yield 88 or over. The better class after-products usually bring such a good price that they are more profitable to sell at once, except in particular cases, as, for example, when it is desired to sell the product from the factory directly to the consumer.

The **better class of after-products** of this class can be made by a special **"covering process,"** if they are too fine-grained and have a very viscous mother-sirup, and so give, by ordinary purging, a slimy sugar of low polarization. By this process, molasses or sirup from a previous purging is run simultaneously with the massecuite into the drum of the centrifugal after it is already in motion, this sirup being of the same purity as that of the mother-sirup of the massecuite. This cover-sirup is so far diluted that it is only saturated, or even unsaturated, and is heated more or less. Usually a molasses of 70°–75° Brix (38°–41° Bé.) is used and warmed up to 50°–70° C. (122°–158° F.). By this means, most of the viscous mother-sirup of the massecuite is washed or forced out by the more

mobile cover-molasses as soon as the massecuite gets on the sieve. Washing and purging is made possible and is very thorough, because of the cover-molasses acting only on very thin films of unpurged massecuite, while, on the contrary, the ordinary cover-sirup method gives only unsatisfactory purging, as the sirup acts on a very irresistant layer, as the centrifugal is full before the sirup is applied. As the whole operation is complete in the minimum time, the dilute molasses has no time to dissolve the grain, and only dilutes the sirup enveloping the crystals which will not purge. In this way a sugar is obtained which is light, easily conveyed, and of high yield, and a molasses with the same purity as that of the mother-sirup.

CHAPTER XXI.

THE PURIFICATION OF CENTRIFUGAL SIRUP.

Before boiling down for the manufacture of "seconds," the different sirups that have drained off are frequently subjected to a purification process. The simplest treatment is, in case they have a too high alkalinity, a **saturation** with carbonic or sulphurous acid gases. If, however, the sirups are saturated to an alkalinity of from, say, 0.02 to 0.04, and the massecuites of the No. 1 product, in consequence, show alkalinity of about 0.05, the alkalinity of the sirup coming from them is not more than 0.05 to 0.10. An alkalinity of at least 0.05 is not only harmless, but is even absolutely necessary, if sirups are to be kept alkaline during the long period of crystallization in the tanks, or during the days of boiling down or crystallizing in the crystallizers. Consequently, carbonatation of sirups in normal process is not necessary and can be omitted, especially as the sirups are diluted thereby and the subsequent expense of evaporating them is increased.

Filtration of sirup before the boiling is frequently regarded as advantageous, because these sirups are always more or less turbid, owing to some precipitation which takes place during the first boiling. Since the weight of these precipitates, which consist chiefly of organic calcium and iron salts (oxalates), is, however, extremely slight (only 0.01 to 0.1 per cent.), and as, even when the sirups are dilute, it is difficult to make them filterable by addition of porous substances, it is obvious that the uses and practicability of filtration are extremely questionable.

It has, in fact, never been proven that there is an increase in

purity of sirups from this operation, although, indeed, it is asserted that the physical properties are improved by filtration preceded by a saturation with sulphurous acid, but proof of this assertion is likewise lacking.

On the other hand, the fact has been established in practice that normal sirups can be worked up to advantage, and give thoroughly satisfactory results, without any filtration or saturation with gas.

Another method of purifying sirup consists in **treating hot, dilute sirup with lime** (or baryta), and subsequent saturation with carbonic or sulphurous acid. Since lime here acts upon the non-sugars, which are present to a considerable extent, just as it does upon the original thin juices, it is clear that a perceptible improvement can be attained by this method only when the original defecation was not sufficiently complete, or was conducted at too low a temperature. It has never been found that the purity of the sirup is increased by the action of lime, but, on the other hand, it is said that after this treatment the sirups are more readily crystallizable, an advantage which, if it is actually realized, is partly traceable to the dilution, since it is easier to boil dilute sirups than concentrated ones, where there is no control used. It is seldom that the unpleasantness of such a further saturation process, and the cost of carrying it out, will be covered by increase in sugar-yield.

If the diffuser-juice has been insufficiently treated with lime, an extremely troublesome and wasteful phenomenon may take place. This is the so-called **froth fermentation of the second massecuites.** This makes itself evident by the massecuites beginning to rise after they are placed in the vats or crystallizers. Throughout the mass, a number of tiny gas bubbles are formed, which cannot escape on account of the viscosity, and hence gradually raise up the massecuite until the whole of it, or, at any rate, the greater part of the upper portion, becomes frothy. Of course, the volume of the mass is increased to the amount of the volume of the gas produced, and, as a result, it runs over the tops of the tanks. The evolution of gas is greatest while the massecuites are still hot;

it diminishes as they cool off, ceases altogether at 60° (140° F.). The amount of gas produced varies greatly; sometimes only a slight foamy layer is formed, while in other cases the space occupied by the gas amounts to from 50 to 100 per cent. of that occupied by the massecuite itself.

The gas evolved consists, either entirely or for the greater part, of carbon dioxide. The *cause* of this **generation of carbonic acid** is not fermentation, although it is so named on account of the fact that, as far as outer appearance goes, it would seem to be such; the fact that the phenomenon is strongest at temperatures above 80° C. (176° F.) shows very clearly that it is not a fermentation. because, at such high temperatures, any micro-organism capable of producing fermentation would be either killed outright or, at least, show a diminished activity. The real cause is to be sought rather in the chemical decomposition of certain organic non-sugars; probably they are decomposition products of invert-sugar, and other organic substances of high molecular weight which get into the juices during working-up of poor beets, particularly those which have been frozen or are decayed. Such compounds may not have been completely decomposed in the defecation, on account of defecating too cold, or for too short a time. After these unstable compounds have collected in the sirups and are exposed to high temperature for a considerable length of time, they begin to decompose, and particularly when the sirups have absorbed oxygen from the air during centrifugation. One of the decomposition-products is carbonic acid, while the other products are, in the main, not volatile, being in fact, for the greater part, non-volatile organic acids, which latter diminish the alkalinity of the sirup, or even give it an acid reaction. If such sirups contain nitrites, as is sometimes the case, the latter will be decomposed by the organic acids, and nitric oxide will be set free with the carbon dioxide. Dark-colored substances are likewise formed which impart a dark-brown color to the whole of the massecuite, as well as to the sugar prepared from it. The formation of foam, furthermore, is in proportion to the number of times the sirup is boiled, and is, therefore, more likely to take place in the manufacture of the third product than with the seconds.

The sugar-yield in such cases will, as a matter of fact, not be greatly affected, but the product is dark-colored, of a fine grain, is neutral or acid in reaction, and usually contains invert-sugar, so that it does not keep as well and is of less value; the same being true of the molasses produced, which likewise contains invert-sugar and is neutral or acid.

To prevent foam-fermentation, a vigorous treatment of diffuser or thin juice with lime in the defecation is to be recommended and is usually effective. Those sirups showing a tendency this way should be boiled under as high a vacuum as possible, at a low temperature, and in some cases with the addition of soda. If these agents do not help sufficiently, the above-mentioned treatment of the sirup with lime will surely be of some use.

As in the case of the juices, many **other purification processes** have been proposed for sirups in which **chemicals,** such as baryta or barium salts, hydrosulphurous acid, ozone, or the electric current, etc., are said to precipitate the non-sugars. No practical results have yet been obtained in this way, and, so long as it is not proven that by these agents it is possible to crystallize sugar from an *actual* molasses, it may be said that they have absolutely no practical significance.

Many like to carry **the sirups** from the firsts, or part of them, **back** to some previous stage of process, putting it, for example, in the diffusion battery, in the raw juice, in the defecation, or in the thin juice. As a matter of fact, there is an increase in the yield of "firsts," when the process is conducted in this way, if the yield is compared with that obtained when the massecuite is not boiled with sirup. The carrying-back of the sirups into the juices then acts favorably upon the boiling, particularly with the juices and sirups of high purity, in so far as the duration of the process is lengthened, because the mixed juices have a lesser purity. If, for example, an amount of sirup of 78° purity, equivalent to 3 per cent. of the weight of the beets, is introduced into juice of 94° purity, the resulting mixture will then have a purity of 91.5°. Slow boiling increases the yield of firsts, as we have already seen. This increased sugar-yield is obtained in a much more simple manner when the

sirups are not introduced into the juices until after the completion of a slow boiling of the pure juice in the vacuum-pan. After its introduction, the massecuite is boiled again for a considerable length of time. This last procedure is always applicable, while the former method can be carried out to advantage only when the juices are very pure, for otherwise a bad grain results, and the sugar-product has essentially poorer properties. It has not been proven that there is purification of the sirup by defecation and carbonatation when it is introduced into the raw juices, although it has been frequently claimed that this is the case; in fact, no satisfactory explanation can be given why this should be so, for it is not easy to see how non-sugars in the sirup can be precipitated or changed by a repetition of the defecation when they have already undergone such a treatment in the thin juice under exactly identical conditions.

CHAPTER XXII.

MOLASSES AND ITS UTILIZATION.

By **molasses** is understood, in the practical sense, that final product in the manufacture of sugar from which, by maintaining all those conditions favorable for a crystallization, no more sugar can be obtained.

The theoretical explanation of the inability of the sugar to crystallize out from the molasses lies in the fact that in it the sugar remains dissolved in the non-sugars, and, conversely, at all concentrations, the non-sugars are held in solution by the sugars.

It is, to be sure, also possible that the cause of a non-crystallization may be due to the viscosity being very great. In such cases, however, this viscosity is caused by too great supersaturation of the sirup, or by too low temperatures; and it can be avoided by a properly-conducted thickening process in the pan, or by the use of high temperatures, but in such cases the sirup is not a molasses in the sense of the definition given above.

The lowest **purity** which has been found in the molasses from a beet-sugar factory is 54° to 55° (equivalent to 51° to 52° apparent). On an average, where the work is conducted carefully, the purity of the molasses is from 58° to 60°, while in many factories it is 60° or higher. It appears that molasses products of higher purity are obtained from the purer sirups. When the purity of the sirup is less than 91° to 92°, molasses under 60° is usually obtained, particularly when it contains organic lime-salts as a result of a vigorous defecation, for the latter diminish the solubility of the sugar. Again, the molasses obtained at the beginning of a campaign, or from the juices first obtained, usually is less pure than

that at the end of the campaign. It is evident from this that the nature of the non-sugars present plays a not unimportant part with reference to the formation of molasses.

Most of the molasses of commerce is not molasses in the strict sense of the word. It may either contain crystallizable sugar, because the last crystallization process has been poorly conducted, when the removal of sugar from the mother-syrup is incomplete, or it may be due to the fact that, during centrifugation, sugar was dissolved by use of too much water or steam.

The composition of a molasses of 60° purity, as it occurs surrounding the crystals in a completely crystallized massecuite, as far as the water and sugar-content are concerned, has already been given. In the condition in which it is thrown off in centrifugation, when the work has been properly conducted, it contains, according to the temperature prevailing at the end of the crystallization, from 13 to 15 per cent. of water. Such a molasses, however, is not marketable, because it is so viscous at ordinary temperatures that it can be neither pumped up nor filled into barrels. It must, therefore, be diluted until the water-content corresponds to about 18 to 20 per cent., or to a density of 81° to 83° Brix (43.5°–44.5° Bé.), and ordinarily this is done immediately after centrifugation by warming it in collecting-tanks by direct steam-injection. After the molasses has been heated and diluted in this way, it can be pumped readily by ordinary sirup-pumps. Molasses which has been stored in vats or pits till it assumes the ordinary temperatures cannot be handled by ordinary pumps even when its density is only 80° Brix (43° Bé.); in such cases it is raised either by means of a chain pump, or by one such as is made for pumping massecuite.

The molasses leaves the factory in barrels or in tank-wagons. It may be worked up into sugar, made into cattle-fodder, or used for the manufacture of alcohol, and for certain other purposes which do no not interest us here.

There were formerly quite a number of different processes used for **obtaining sugar from molasses,** of which all those using alcohol as a solvent, or that were otherwise expensive, disappeared with the

dropping of sugar prices. To-day there is, with the exception of the strontia method, which is only used in sugar-refineries and not at all in beet-root factories, no method of practical importance other than those of osmosis and precipitation.

Osmosis depends upon the fact that the different components of the molasses possess a very different diffusion capacity. Since not alone the non-sugars, but also the sugar itself, is diffusible, it is evident that osmosis can only effect the separation of the molasses into a sirup of high purity, and into the so-called *osmosis-water*, which is a sugar-solution of less purity than the molasses itself. The action of osmosis is more or less satisfactory, according to the nature of the non-sugars present in the molasses (or rather in the low-grade sirup, for molasses itself can be seldom subjected to osmosis with advantage). Inasmuch as the salts of the alkalies diffuse most readily, it follows that sirups with a high ash can be improved by osmosis. Consequently the efficiency of osmosis differs not only in different factories, but in the same factory in different years. Some sirups will not give good results even when but one osmosis is attempted, while others can be subjected to the process twice in succession. Naturally, however, the second time will never give as favorable results as the first, for the reason that those parts of the sirup which diffuse most readily have already been removed.

On the whole, then, it may be said that, on account of the slight action at the best, osmosis is only advantageous under particular conditions, for example, in countries where the evaporated osmosis-water can be sold profitably to the distillery. In Germany, wherever osmosis is still employed, the simple osmosis apparatus is still used; in Austria, on the other hand, this apparatus has been improved considerably in certain respects. These **improvements** consist chiefly in the following details: The paper surface is made as effective as possible; the canals are arranged so that they will not become stopped up; the proper relation between the water and the sirup that enters is constantly maintained; the sirup and water layers are made as thin as possible; the difference of density between the two liquids is kept as great as possible; the temperatures are maintained high, and the method of discharge is a good

one. Of course, great stress is laid upon the quality of the osmosis-paper.

With regard to the method of using the osmosis apparatus, it is so very simple that we need not go into a discussion of it here, and its use is now so limited in Germany that it has become a matter of little interest.

The pure sirups obtained by osmosis are boiled down and brought to crystallization at a high temperature. The sugar product thus obtained is relatively low in ash, but rich in organic non-sugars, so that it is not so marketable as the firsts and brings a lower price. The final molasses produced is also of lesser value and cannot be utilized for another desugarizing process, because it gives products of low grade and is lacking in those salts which play an important part in making the strontia method effective, for example, as well as those useful at the molasses distillery.

The **precipitation process** is the best for the recovery of sugar from the molasses whenever there is an abundant supply of cold water, at a temperature of not over 10° to 12° C. (50° to 54° F.), because it is so simple that it does not cost much to carry it out, and yields pure juices with small sugar losses and adapts itself well to the regular factory work.

The lime used in the process must be as pure as possible, containing but little magnesia. Freshly-burned lime is much more effective than that which has been kept for some time. Particular stress is laid upon pulverizing and sifting the powder, because less lime is used in proportion to the fineness of the powder. For this reason, lime that is soft and easily pulverized is especially suitable for the process. Brass sieves, Nos. 110 to 120, are used for sifting.

In carrying out the process, molasses at 14° Brix, and sometimes much more dilute than this, is put in mixers and cooled down to the temperature of the cold water. It is important that the liquid should be violently stirred or kept in motion at this stage, so that the heat will be quickly given up to the cooling surfaces, and the powdered lime introduced be mixed uniformly with the liquid. The more rapidly this is accomplished and the finer the lime powder is, the sooner the lime com-

bines with the sugar to form the insoluble sucrate, whereas, if the powder balls up and is changed to hydrate, it becomes inactive. The greater the amount of lime that becomes inactive in this manner, the greater the amount of heat produced; and consequently the liquid must remain in the cooler for a longer length of time, which gives greater chance for the lime to become slaked. It is advisable, therefore, to carry out the process rapidly, not only in the coolers but later in the presses, on account of the readiness with which the precipitated saccharate is decomposed.

In order to prevent the balling-up of the lime into lumps, it has also been proposed to introduce the lime little by little by sifting the powder, in the form of a fine dust, over the whole surface of the liquid, or by blowing it into the mass with fans. In this way a somewhat smaller amount of lime is required.

In the ordinary method of working, as a rule, about 80 to 120 parts of lime are used for 100 parts of sugar, or, in other words, from two to three times the theoretical amount necessary for the formation of the trisucrate of lime, and the quantity increases as the water is warmer, the lime coarser, and the extent greater to which the removal of the sugar from the final lye is to be carried. It is not known what the exact composition of the precipitated sucrate is; at all events its properties are different from the trisucrate formed by boiling lime with sugar-solution.

The sucrate formed in the cooler must be immediately filtered off under slight pressure in filter-presses with large compartments, in order that the cake can be washed readily. The washing process is carried out in the same way as in the other filter-press work; but particular attention must be paid to the changing of the filter-cloths as soon as they begin to harden, and the wash-water must be as cold as possible. If the amount of wash-water is kept proportionally small, the sugar-losses in the lye will be diminished, because all the wash-waters, together with some of the original mother-lye, may be used for diluting the molasses.

All experiments with the object of working with concentrated molasses, so as to obtain small amounts of concentrated lyes which can be evaporated to advantage and worked up for the potash

salts, have miscarried: either an impure sucrate, hard to wash, is obtained, or there is a poor sugar-yield.

The older method of precipitating a part of the sugar contained in the first lye, by heating it, is only used where it is considered advisable to obtain a charcoal by evaporating and calcining this lye, for in such cases there must be precipitation of the lime. Usually this first lye, which amounts to 80 to 100 per cent. of the molasses, is thrown away, or utilized as fertilizer.

Working the sucrate into the regular process is best accomplished after it has been partially decomposed. If the sucrate, when discharged from the presses, is carried by means of a screw-conveyor to a vessel provided with stirrer and there mixed with thin juice, it decomposes into the monosucrate and calcium hydrate. The mixture acts very energetically in the defecation process directly upon the diffuser-juice, and there is no danger of forming, even at temperatures above 70° C. (158° F.), the practically insoluble trisucrate, which is decomposed with difficulty by carbonic acid, and would render the scums rich in sugar. This insoluble trisucrate, that is formed at high temperatures only, results when the precipitated sucrate is added to the hot, raw juice in the form of a thick and cold paste.

Beet-sugar factories which only work up their own molasses are accustomed to add with the sucrate from 2 to 2½ per cent. of lime to the beet-juices, or exactly as much as is usually used for defecation. When it is, however, considered advantageous to buy molasses and remove the sugar, this amount of sucrate would give too much lime for defecation, and the carbonatation would be unnecessarily burdened. In such cases it is advisable to mix the excess of trisucrate with considerable thin juice, and to then filter off the precipitated calcium hydrate, which can be done without difficulty, in filter-presses. After sweetening off, this calcium hydrate may be added to the dilute molasses in which it dissolves with the formation of the monosucrate, and hence caustic lime will be saved.

Although this precipitation process is a desirable one for the recovery of sugar from molasses apart from working-up of beets,

on account of the ready decomposition of the sucrate, yet the chief advantages are obtained only when it is carried out in connection with the beet-work, because these sucrates furnish without additional expense the requisite amount of lime for a good defecation, while the other expenses of operation, where this mutual advantage is gained, are very slight.

While the sugar-liquors recovered from the sucrate usually have a purity of 90° to 94°, which is at least as high as that of the beet-juice, it is nevertheless true that these juices are *less readily crystallizable* than those obtained directly from the pure beets. For this reason it is a fact that the yield of firsts from massecuites is, with equal purity, always greater in those cases where the pure beet-juice is worked up than when it has been mixed with sucrate. It appears as if this lack of tendency to crystallize is caused by the presence of certain injurious non-sugars, and in particular certain lime-salts, which are not removed by defecation, but remain in the sucrates and are constantly carried back to the beet-juice. Consequently the amount of these substances steadily increases (especially the raffinose, which is precipitated by the lime), so that its action upon the crystallization tends to increase from year to year. It is, therefore, absolutely necessary that once in a while the residual molasses shall be thrown out altogether, say, perhaps, every two or three years, depending on the quality of the beets.

If these precautions are taken, the diminution in the yield of firsts, as well as the injury to the quality of the sugar, is kept within certain limits; although it is unquestionable that this change in the nature of the product is disadvantageous for refining. This method of purifying the molasses is successful only as long as the raw sugar obtained is not valued at a price lower than that brought by pure raw sugar.

Electrolytic processes have been recommended for extracting sugar from molasses as well as from juice, employing dialysis through a membrane. These processes have considerable interest, as they attempt to recover not only large amounts of sugar but non-sugars as well, and it is in the latter that the profit

is looked for. A membrane impermeable to sugar and a peculiar mercury cathode are used. The alkali metals set free by the electric current at the cathode dissolve in the mercury which is being continually removed from the cathode space. In the upper half of the apparatus, the amalgams of the alkali metals are decomposed by water, the mercury constantly flowing back to the cathode. Acids pass through the membrane to an iron anode where they form iron salts which all the time are being converted to lime salts by added lime, and separate out as the solution concentrates.

The purity of the molasses only rises to 75, so that only a small amount of sugar of little value is recovered. Whether there is sufficient profit in the by-products to make the process pay is very doubtful.

The Use of Molasses as Fodder.—The **food-value** of molasses depends for the most part upon the sugar-content, and also to some extent upon action of salts upon digestion. It is, therefore, not only an easily-digested food, but also a condiment, exciting the appetite of the animal, and causing it to eat and digest forms of fodder it would not care for without the molasses.

Since the great viscosity of molasses in the cold condition diminishes its value as a fodder, particularly when used on small farms on which necessary arrangements for warming and diluting are wanting, it is usually preferable to **mix** it with turf-meal, or other fodder which will absorb the molasses. Such a mixture forms a dry and more or less brittle mass which can easily be broken up into small pieces.

The mixture is usually prepared at the sugar-factory by means of suitable machines for mixing the absorbent material with the hot molasses. The temperature of the molasses should not, as a rule, exceed 80° C. (176° F.), because otherwise the fodder cools down too slowly, and frequently there is an after-heating if the mixture is stored in heaps. When the molasses is mixed with malt-germs, or any similar substance which turns brown on heating or has an acid reaction, the temperature should be kept below 80° C.

When the fodder has thus been mixed, it must be completely *cooled* in flat heaps before it can be placed in bags or in larger heaps. It is best to use the fodder as soon as possible after its preparation, for it has a tendency to spoil on keeping. A moist molasses-fodder spoils readily, and is then injurious to the animal. The molasses should not be heated by introduction of live steam, but by closed coils, if it has already been diluted to 80° Brix. A fodder prepared by using a molasses of, say, 78° Brix, does not keep so well and separates readily from the mixture, particularly in summer.

CHAPTER XXIII.

THE BOILER-HOUSE.

This is not the place for going into a detailed discussion of the economy and technique of the boiler-house and the firing, but only those points will be brought out which are peculiar to the conduct of the boiler-house of a sugar-factory. First of all, it must be emphasized, however, that, if there is to be economy observed in the use of fuel, there must be a good system of boilers, properly-arranged grates with good firing, and the boiler-house must be in constant touch with the factory work. As it is always difficult to obtain good firemen for the short working period of a beet-sugar factory, mechanical stokers have been introduced to a considerable extent, which permit the utilization of less expensive forms of fuel. Connected with these artificial stoking arrangements there should be an apparatus for mechanical transportation of the fuel. The work necessary in superintending the operation of this machinery must be carefully done, such as, for example, weighing the fuel, measuring the feed-water, examining the flue-gases by taking special samples, or sampling by a mechanical device; controlling the steam-pressure by recording manometers, measuring the temperature of the boiler feed-water and of the flue-gases by self-recording thermometers, and controlling the draft by measuring it at the boilers and in the chimney.

Since beet-sugar factories require their fuel just at a time when other users are in great need of coal and the business of the railroads is very much rushed, it is necessary to arrange a large part of the coal supply for summer delivery. In the case of lignite coals such early delivery should be avoided as far as pos-

sible. They keep well only when piled in a compact mass which is not feasible if the delivery is not practically all at once. Even many other kinds of coal lose in value when not stored carefully in appropriate manner. They become heated by oxidation of iron pyrite and hydrocarbon constituents and often become ignited. To prevent heating, it has been recommended to drench the coal with plenty of water, if its temperature rises above 50° (122° F.). Air cooling is not recommended, as the air circulation will be greatest where the coal is hottest.* The surest means of quenching already ignited coal is by means of carbon dioxide. Coal storage under cover is very desirable but expensive. In all cases of prolonged storing of coal it is necessary to keep constant watch of its temperature as observed from thermometers inserted in the heaps, so that timely precautions can be taken should a steady rise in temperature be shown.

The **particular conditions prevailing in the boiler-houses of a sugar-factory** are partly favorable and partly unfavorable. It is very advantageous to have a **supply of pure and hot feed-water,** which is furnished by the distilled water from the evaporating-pans. The temperature of this water is determined by the pressure under which the steam is condensed. The hottest water comes from the heating-chambers of the juice-heaters and the first member of the multiple effect, and has a temperature of from 110° to 120° (230° to 248° F.). In some factories this hot water is collected under pressure in closed retainers, and is pumped separately from the other water into the boilers, so that it still has a temperature of something over 100° (212° F.) when it enters the boilers. Since, however, this very hot water is insufficient in quantity, and it is necessary to utilize the condensed steam from the other apparatus, which have a temperature of less than

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* This is not in accord with American practice. Coal here is kept as dry as possible, moist coal being considered a greater fire risk. The practice of the large coal companies here is to dig out the hot coal and expose it to the air by moving the heap. Small steel flasks of liquid carbonic acid which are closed with fusible plugs are sometimes placed in the heaps.—TRANSLATORS.

100° (212° F.), it is evident that all of the feed-water may be collected together in the same vessel to advantage. In this way the hottest water becomes mixed with the coldest, and the temperature of the mixture is in the neighborhood of 100° C. If the condensed vapor from the sirup effects, which have temperatures around 75°–80° (167°–176° F.), is only used in exceptional cases for feeding the boilers, but is ordinarily utilized for other purposes in the factory, then the temperature of the feed-water should not sink below 90°–95° (194°–203° F.). The pumps required for feeding the boilers work without any trouble with the hot water if they are provided with check-valves on the suction-pipe, and if the water runs to the pumps.

This hot water of condensation may frequently contain substances which will act injuriously upon the boilers, such as, for example, sugar and oil. The ammonia contained in the condensed water, on the other hand, exerts no injurious effect, but is helpful, if anything, as an alkali.

Injuries to the boilers caused by sugar may be of two kinds, namely, either of a chemical or of a mechanical nature. Which influence makes itself most felt depends upon the amount of sugar reaching the boilers. If only extremely small quantities of sugar are fed into the boilers little by little, then the sugar becomes decomposed more or less quickly, according to the temperature of the water in the boiler, and acids of different compositions are formed without precipitation of perceptible amounts of solid decomposition products. If large amounts of sugar enter a boiler at any time, the sugar becomes burned at the hottest portions of the tubes; and in this way a layer of porous charcoal is formed whose thickness increases so rapidly that the metal under it becomes overheated, and, on account of the pressure exerted from within, bulges out. Such action may be produced by a layer of but a few millimeters in thickness.

This sort of injury to the boiler by the introduction of water containing sugar is by all means the most serious that can take place, because it is effected very rapidly, and within a few hours after any large amount of sugar has passed into the boiler. There

is no remedy for this, other than to **shut down the whole boiler-house immediately,** or to cut out that boiler containing the sugar and blow off the boiler-water. There should be no hesitation in such cases to resort to extreme measures; for the troubles in the other parts of the factory, which may result from shutting-off of the steam, are by no means so serious as the harm which may be done by bulging the boiler sheets during the campaign. The higher the steam-pressure within the boilers, the more rapid is the decomposition of any sugar present; consequently, in the the case of boilers with high steam-pressure, particular attention to this detail is required. If the bulges are not too deep, and the boiler-plate is of good material, it is often possible to force back the swelling, and in a short time make the boiler in good condition again. In all cases this inexpensive method of getting over the difficulty should always be tried before going to the tedious and troublesome work of changing tubes or plates.

If the given precautions are taken with respect to juice-leaks in the evaporating-plant, and if the condensed water of the preheaters, in which the vapor-pressure is greater in the juice-space than in the steam-chambers, and that from the vacuum-pans, be not taken for the boiler-feed, one can feel fairly certain that, in the ordinary conduct of the work, no large amount of sugar will get into the boilers. The state of affairs is quite different when there are *troubles* in evaporation or vacuum-pan plant, and the vacuum off the apparatus so that the pressure in the juice-chamber is equal to that in the heating-space. Then, if there is a leaky pipe or a steam-coil, it is easily possible for large amounts of sugar to get into the steam-space and thence into the boiler feed-water. Consequently, when there is any such trouble in the factory, the feed-water should be immediately examined to see if it contains sugar, first of all by tasting it, then by a laboratory test. In case an appreciable quantity of sugar is found, it is unsuitable for the boilers, and fresh water must be used in its place.

The second kind of injury that may be produced by the sugar is of a *chemical nature*, and the nature of this is a corrosion brought

about by the action of the acids produced in the decomposition of the sugar upon the boiler-plate. The nature and extent of the corrosion depends, in the first place, upon the amount of sugar in the boiler, then upon the steam-pressure, or, what is the same thing, the temperature, and, finally, upon the duration of the action. The higher the temperature of the water in the boiler, the more rapid will be the conversion of sugar into these acids. Whereas, in boilers used merely for boiling purposes in which the temperature as a rule does not exceed two atmospheres (30 lbs.), the sugar is only slowly decomposed, in those boilers with high-pressure steam of, say, six atmospheres (90 lbs. = 164° C. or 327° F.), it takes place very rapidly, as the acids formed by the decomposition act energetically upon the iron at these high temperatures and corrosion is rapid and considerable.

It is absolutely impossible to prevent the introduction of small quantities of sugar into the boilers during the progress of the work. In order to prevent these injuries, the boiler feed-water must be made *alkaline by addition of soda*, and this alkalinity must be regularly tested at every water-cock and in each boiler. This alkalinity should not be made too high, as in that case the boiler-water foams too much; as a rule, an alkalinity is desirable such that 100 c.c. of the boiler-water, when titrated with rosolic acid as indicator, will require 10 c.c. of tenth-normal acid to neutralize it. If suddenly the alkalinity is found to be greatly diminished, it is a sign that sugar has gone into the boiler, and in fact the amount of sugar can be calculated by the diminution in alkalinity; 0.0114 gram of sugar will produce enough acid to neutralize 1 c.c. of tenth-normal alkali, or two kilograms of sugar are equivalent to approximately one kilogram of sodium carbonate (soda).

It is absolutely necessary to examine the water in every water-cock *of each boiler*, for it is easily possible that one boiler may contain more sugar than another boiler, because of the fact that it has just been fed with water containing sugar. Furthermore, an immediate examination of the water in all of the boilers is necessary when the well-known odor of decomposed sugar is perceptible in the steam, or if there is a noticeable increase of color

in the boiler-water and it begins to foam strongly. A dark coloration of the boiler-water is of itself not harmful as long as the water reacts alkaline.

A certain amount of protection against the action of the sugar is afforded by a *mineral layer upon the boiler-plates.* There is always slight scale, on account of the fact that, at the beginning of the campaign as well as on Sundays, the boilers must be fed with spring-water, and the salts contained in it are gradually deposited upon the boiler-plates. This scale is, however, not to be relied upon, as frequently the deposits become loosened and drop off.

Rules for preventing injury to boilers by sugar may be summarized as follows:

1. Use condensed water from the evaporators only for feeding boilers; and examine for sugar before it is used, not only at the beginning, but always when the vacuum in the evaporators is abnormal through any trouble in the factory.

2. Maintain a definite alkalinity of the boiler-water by adding soda to the feed, and regularly examine the water in each boiler for alkalinity.

3. Cut out at once any boiler in which, in spite of the precaution above mentioned (2), tne boiler-water suddenly shows an acid reaction, or if it becomes dark-colored and foams badly.

4. Immediately examine the boiler-water as soon as the well-known odor of decomposed sugar is perceptible, or when the indicator glasses in the side of the boiler show that the water is becoming dark-colored.

5. The boilers should be fed at the beginning of the campaign with spring-water, so that a protecting layer of mineral deposit will be formed upon the boiler-plates.

6. Condensed water should not be used for feeding the boilers at the beginning of the campaign, until it has become perfectly clear and colorless.

The water obtained from the condensation of the engine-exhaust contains some of the **oil** which was used for lubricating the steam-cylinders. Since vegetable or animal oils or fats would be saponified

by the hot water in the boilers into free fatty acids, and the latter would attack the iron, it follows that oils of this character should not be used. This causes no trouble, because it is possible to obtain suitable mineral oils which are composed of pure hydrocarbons and cannot form acids. Even oils of the latter type, however, can cause harm if they enter the boilers in large amounts, because they store up heat and thus make steaming more difficult, and tend to form tough lumps with the loose scums that are present in almost every boiler-water. These lumps tend to deposit on the heating-tubes and prevent the heat-transference to the water, so that the plates may be overheated.

Such troubles can be prevented best by an apparatus for removing oil placed in the exhaust-steam pipes before they reach the evaporating-pans, which serves to remove the greater part of the oil; in this way any injurious action of the oil in causing overheating of the boiler-plates is prevented. Filters arranged so as to filter off the oil from the water have not proved practical. A part of the oil may also be removed by collecting the boiler feed-water in tanks provided with an overflow. The finely-divided oil in the water then has time to collect to a considerable extent upon the surface of the water and there overflow. It is self-evident that it is desirable not to use too great an amount of oil in lubricating the cylinders, as an excess tends to increase the amount that is carried over into the condensed water.

The **oily scum** has an unpleasant action in still another respect. Before it settles to the bottom it floats in the form of a loose mass, and often stops up the water gauges. This difficulty may be overcome by placing a bent piece of sheet-metal inside on the front head of the boiler, extending perpendicularly in front of the water-gauge supports, dipping into the water down to the heating-tubes and nearly reaching up to the top of the boiler. In this way a place is formed where the water is relatively quiet, so that any scum which might enter from underneath must again sink to the bottom, while at the top there is no danger of any scum getting in, even when the contents of the boiler foam badly.

The escaping **gases of combustion** have usually a temperature

of 200°–300° (390°–570° F.), but often owing to the forcing of the boiler as high as 400° (750° F.). The temperature is always lower at the beginning of the campaign than at the close, as it is increased by the poorer heat transference due to scale in the boilers and rust on the tubes. This large amount of heat can be utilized by placing a feed-water heater in the main flue, which reduces it to 140°–150° (284°–302° F.), or by a tubular superheater. Feed-water heaters have often proved their utility, but placing them in the main flue has now been given up, since at that point the heat is too low, too much heating surface being necessary. Superheaters are now nearly always built where the temperature of the gases is about 500° (930° F.), or directly behind the boiler-tubes.

In some boiler-houses boilers using high-pressure steam are placed beside others of lower pressure, the former furnishing steam for the engines with a pressure of six to eight atmospheres (90–120 lbs. steam-pressure), and the latter steam for evaporating purposes with a pressure of only two or three atmospheres (30–45 lbs.). This **boiler division** originated because newer boilers are constructed for higher pressures than the older ones and when it is desirable to still utilize the latter there is no objection to the arrangement. If, on the other hand, it is believed that the work is more advantageously conducted when this is done the idea is erroneous. With a definite amount of coal nearly as much steam at six atmospheres' pressure is produced under the same conditions as at three atmospheres, for although the difference in temperature between the heating-gases and the contents of the boiler is about twenty degrees less in the former case, yet the amount of heat taken up is not much greater, because the transmission-coefficient increases at the higher temperature. The amount of heat lost by being carried away by the flue-gases is, therefore, about the same in both cases. Furthermore, steam at six atmospheres can be changed into a pressure of three atmospheres by means of a reducing-valve without the loss of any heat. It is evident, therefore, that there is no particular advantage to be gained by dividing boilers into two systems, and it certainly has disadvantages, particularly because it requires more attention.

A battery of boilers of which all are at the same pressure can be fired to much better advantage than when there are two series of boilers, one at a higher steam-pressure than the other. The demands of one are quite different from those of the other, and it is much harder to run boilers of a divided battery economically and fire them properly. If the irregularities in the use of steam in the factory are distributed throughout the whole boiler system, or, in other words, upon practically three times as many boilers than when two systems are used, then the firing need be only slightly increased or diminished to meet the new conditions, and it is done uniformly. In a separated system of boilers a double system of steam-piping is necessary, and the cooling-losses are greater than when one pipe of large dimensions is used.

Particular attention must be paid to the boilers after the campaign is over. As the boilers are used only two or three months in the year, and the remaining time are cold, they are likely to suffer in common with all other iron parts in the factory by corroding badly, unless particular precautions are taken. The best means of preventing the formation of rust, both on the inside and outside of the boilers, and particularly in the flues, is to thoroughly clean and dry them. The flues must be thoroughly freed from flue-ashes and soot, the scale on the inside of the boiler removed, and finally all the boiler and masonry must be thoroughly dried by small fire. It is not advisable to cover the boiler with any rust preventative; sometimes it is recommended to cover the inside with tar, but it is very doubtful whether this does much good, and there is danger to workmen, as the hot tar readily evolves combustible gases. Similar care should be given to the superheaters and feed-water heaters, after the campaign, as to the boilers.

CHAPTER XXIV.

THE LIME-KILNS.

OF the **different types of lime-kilns** two have proved most suitable for the sugar factory: the so-called *Belgian kiln*, which is heated solely by means of the coke which is thrown into the kiln from the top together with the limestone, and the *kiln with regenerator firing*, in which the heating is wholly or in part produced by means of an exterior hearth. In general it may be said that less fuel is required by the Belgian kiln; since, however, it is necessary to use good coke with as low ash as possible, while the other type permits the use of a cheaper grade of fuel, there is practically no difference in the expense of operating.

A good lime-kiln, or -burner, when worked properly, should yield well-burned lime and a saturation-gas rich in carbonic-acid gas (carbon dioxide).

Choice of limestone is by no means a matter of minor importance to the industry, although its suitability cannot be determined in many cases by chemical analysis alone, because usually the analytical results do not show whether it will be difficult or easy to convert the limestone into lime, or whether the impurities will exert a harmful influence. This is determined more readily by the outer appearance and structure of the limestone, and the injurious effect of impurities does not so much depend upon the amount present as upon the way they are distributed throughout the mineral. At the same time it is safe to assume that a limestone in which the chemical analysis shows the presence of considerable quantities of foreign constituents is less suitable, and whenever possible it should be replaced by a purer variety. These *impurities* are capable

not only of contaminating the juices in defecation, but they may cause trouble in the lime-kilns. The presence of silicic acid has the effect of strongly lessening the slaking power of the lime; in some cases as little as six per cent. of silica will cause the lime to become "*dead burned*" in a short time, so that it will not slake quickly with evolution of heat. Alumina, iron, and manganese of themselves do not exert any harmful influence, but when iron is present, together with alumina and silicic acid, it favors the decomposition of any clay, and there is a tendency towards "dead burning." The presence of sulphur either in the limestone or in the fuel is always harmful, because it causes formation of gypsum (calcium sulphate), and the latter acts injuriously upon the lime. Alkalies, which are usually present only to an inappreciable amount, can cause harm if they exist to any extent in certain parts of the limestone, for they aid the decomposition of other constituents by acting as a flux. Naturally, the action of all these impurities depends upon the duration of the lime-burning and the temperature as well as upon the structure of the limestone.

Burning of limestone accomplishes dissociation of calcium carbonate into calcium oxide and carbon dioxide (or carbonic-acid gas), and, like all such dissociation phenomena, it depends upon the temperature and pressure of the gas. At a temperature of about 800° C. (or 1475° F.) there is already slight dissociation, but it becomes appreciable only when 900° C. (1650° F.) is reached. At temperatures below this decomposition point, which is a dull-red heat, the burned lime has a strong tendency to absorb carbon dioxide, although, as is well known, it does not do this at ordinary temperatures when exposed to *dry* carbon dioxide. For this reason it follows that the carbon dioxide set free must be removed as fast as possible from the kiln. The tendency for any chemical reaction to take place completely is always greater when one of the products of the decomposition is removed.

For practical working of lime-kilns it is always sufficient to heat the limestone for a few hours at a temperature somewhat over 1000° C. (1850° F.). The highest temperatures that should be attained in the burning are between 1200° and 1300° C. (2200°

to 2375° F.). This is sufficiently high to completely convert large pieces of limestone into lime. Higher temperatures should be avoided, particularly for any long period of time. Even perfectly pure calcium carbonate, when decomposed by five or six hours' heating at temperatures of about 1600° C. (2900° F.), becomes converted into a condition such that it does not slake with water until it has stood in contact with it for about one day, being practically dead burned. If it contains small amounts of silicic acid the same effect occurs at lower temperatures and in shorter time.

The **size of the burner,** or kiln, depends upon the amount of lime which it is desired to produce in 24 hours. When it is cheaper to buy the lime than to make it, only an amount sufficient to yield the necessary quantity of carbon-dioxide gas should be burned. Since for burning 100 parts of limestone about 10 or 12 parts of fuel are required (coke or coal), and there is about the same weight of carbon in 12 parts of coke as in 100 of limestone, it follows that about half of the carbon dioxide comes from the coal and the remainder from the limestone. If, then, the gas from the kiln contains twice as much carbonic acid as was originally present in the limestone, and say two-thirds of the gas that is passed into the juices during carbonatation is actually utilized, it follows that the carbonic acid produced by the kiln will saturate, or carbonatate, about one-third as much more lime as is produced by the kiln. This additional amount of lime can be purchased.

The size of a lime-kiln is also regulated by the capacity of the gas-pump. The more rapidly the gas is removed from the kiln the quicker is the conversion of limestone into lime and the higher the layer which reaches the maximum temperature of about 1200° C., and, in fact, this maximum temperature is higher for the same reason. The greater the activity of the kiln the greater the yield of both lime and carbonic acid, while the consumption of fuel is relatively less. The zone of maximum temperature is larger when the burner is taller with correspondingly smaller diameter. The kiln should be not less than 30 feet high, and the diameter may be calculated with regard to the amount of lime that it is

desired to produce. It is obvious that the zone of decomposition should be so placed that the hot gases drawn off will be sufficiently cooled by their passing through the limestone above it, and, at the same time, this upper layer will receive the proper amount of pre-heating. Particular attention must be paid to this point in the case of the Belgian kiln, in which the decomposition-zone sometimes is too high and often too low. In the same way it is necessary that the cooling-zone below should be deep enough to have the lime cooled down sufficiently at the time of its removal from the kiln.

The jacket, or masonry surrounding the kiln, should be air-tight and the observation-holes, through which pokers may be introduced to remove lumps of lime from the side of the kiln, must also close tightly, so that the outer air cannot enter, and it is equally desirable to prevent much of the carbonic acid from escaping into the air.

It is well, though not absolutely necessary, to break up the limestone into small pieces of uniform size. If the kiln is working with considerable activity this breaking up of material can be omitted, particularly if labor is high. Under no circumstances should the limestone waste be thrown into the kiln, because the latter, particularly when the kiln is not very large in diameter, is likely to cause the contents of the kiln to settle into a compact mass, so that the kiln will not draw well. The coke that is put in with the limestone should be well broken up, so that it will be actually consumed in the decomposition-zone and not partly in the cooling-zone.

Withdrawal of lime from the kiln should be at not too long intervals, preferably once every four hours. Thereby the contents of the kiln are more frequently set in motion and the lime does not remain too long in the decomposition-zone, so that there is less danger of its becoming "dead." It is very satisfactory to remove the lime continuously by means of a mechanical device similar to that used in the bonechar-burners. The sticking of lime to the lining of the kiln is usually caused by the formation of slag. The limestone forms an irregular arch over these places,

which must be broken up by long pokers introduced through the observation-holes. Sometimes the pieces of rock are so firmly united that it requires several hours' labor to bring the kiln back to a satisfactory condition.

Immediately after the lime has been withdrawn at the bottom, the kiln must be fed at the top. This refilling of the kiln must take place as quickly as possible, because during this time the gas becomes mixed with more or less air which is sucked in, and in this way the carbonatation takes place more slowly when such gas is used. The limestone and coke should be reduced to a uniform size. Mechanical contrivances are very advantageous for charging kilns with limestone and coke and for continuous removal of lime, as they save labor and make the working of the kiln more uniform, likewise relieving the workmen of the heat and dust.

Special attention should be paid to the manner of **charging kilns.** The kiln is first dried out for several days by a slow wood fire. In the preliminary firing, the space next the fire can be filled with limestone alone, this being mixed with coke higher up. Preliminary firing is started slowly and pushed only after the masonry is warmed sufficiently. After 24 hours, you can begin to take the lower layers of stone out, and after 48 hours, good lime can be drawn if the pumps work well.

In the Belgian oven a base of limestone is first built up to the discharge openings and shavings or brush and wood chopped fine thrown over this to a depth of from three to six feet, and then a layer of coke. Above this is started the regular charge of limestone and coke in proper proportion: (10–12 : 1). It is advisable to use somewhat more coke for the lower layers and at first not to fill the kiln entirely full. After the wood is kindled and the fire come up so that the limestone is red hot, the gas pump is started and the kiln wholly filled. The drawings are now begun, at first somewhat less than the usual size, and working thus in two days after firing well burnt lime and a rich saturation gas are obtained.

The carbonic-acid gas from the kiln contains the gases of combustion and the carbonic acid from the decomposition of the limestone mixed with more or less soot from the fuel. The gas on

leaving the kiln has a temperature depending upon the height of the kiln, but this temperature should never rise so high that the exit-pipes become red hot. Before the gas can be used for carbonatation purposes it must be cooled and freed from objectionable impurities. For this purpose a **mechanical purification by means of a washer** (" **Laveure** ") is sufficient, for the gases other than carbonic acid that are present, such as oxygen, carbon monoxide, nitrogen, and sulphurous acid, do not exert any unfavorable action upon the juices; sulphurous acid, in fact, has an action very similar to the carbonic acid itself. Such constituents of the gas, therefore, need not be removed. When there is not enough air introduced into the kiln there is more or less sulphuretted hydrogen formed which has an objectionable effect upon the juice; the formation of this gas, however, may be entirely prevented if the proper attention is paid to the kiln during the lime-burning by not allowing the reducing-zone to become too large and not letting the coke that is thrown pile up. Hence there is no particular need to attempt to remove sulphuretted hydrogen.

The gas-washers serve not only to *cool* the gas but to *free it from cinders, and the distillation products of the coal.* They consist of cylindrical reservoirs made of iron, wood, or cement. Since the iron is often strongly attacked when there is an insufficient amount of water in the washer, wooden or cement vessels are usually preferred. Washing is best effected when it is conducted on the principle of counter-currents, by allowing the water to circulate in the opposite direction to the gas which enters at the top of the washer, and by using a suitable distributing material such as coke. Water should always be allowed to settle at the lower part of the tank by placing the overflow about sixteen inches above the bottom, so that the hot gases on entering the washer at the bottom first pass through this layer of still water. As water absorbs carbonic acid the amount used for washing should be kept as small as possible; the inflow of water is regulated so that it will always run off hot at the overflow to gain a further advantage that hot water absorbs much less gas than does cold water. Even then the gases are well cooled, because they always come in contact

with the cold water in the upper portions of the washer. When the gases are well cooled the gas-pump becomes more efficient, because the cooler the gas the smaller its volume.

The efficiency of the gas-pump is also increased by making the friction in the washer and in the piping as small as possible. The suction-pipes, particularly the one that carries hot gases from the lime-kiln to the washer, should, therefore, be large in diameter, and, also, when the gases reach the water they should not be obliged to overcome the pressure of a very high column of water. The total reduction of gas-pressure in the piping before the pump is reached should not be more than that corresponding to a column of water three feet high. In order to control this reduction of pressure it is advisable to insert in the piping in front and behind each washer, as well as at the pump itself, vertical glass tubes which dip into water at the bottom. These tubes show the vacuum at the different places, and in this way the loss in pressure at the different pipes and in the washer can be determined readily. If the water oscillates up and down in the tubes to any considerable extent it indicates irregular washing. In order to prevent any of the water which has been carried along from the washer from getting into the pump it is well to place a water-trap in the piping. It is not feasible to pump hot or dry gases owing to the excessive lubrication of the pump-cylinders necessary. The trace of dust which remains in the gas even after washing forms a greasy substance with oil which hardens after a while and interferes with the working of the pump, and makes other troubles. Hence, the gas is best pumped moist, or is moistened in the pump-cylinder by water which also serves as a lubricant; so oil is not needed.

Saturation or carbonatation gas is *richer* in *carbonic acid* when limestone is burned with a small amount of fuel and with but a slight excess of air. In the most favorable conditions, when the limestone has been completely burned with 10 per cent. of coke, it is possible to draw off from the kiln a gas containing 37 per cent. by volume of carbonic acid, while with a consumption of 12 per cent. of coke, and under otherwise perfectly similar con-

ditions, the gas will only contain 35 per cent. of carbonic acid. In many lime-kilns the gases contain from 30 to 35 per cent. of carbonic acid, but this percentage fluctuates because the production of the gas is, of course, greater shortly after the charging of a kiln than it is later. As a rule when the gas contains from 25 to 30 per cent. of carbonic-acid gas it is considered satisfactory, and this is usually obtained with generator-burners. In fact, many people hold that the carbonatation requires more time when the gas contains more than 25 to 30 per cent. If this is known to be the case from practical experience (although it is scarcely probable theoretically) it is not advisable to diminish the efficiency of the kiln by introducing more air into it, but rather the gas should be diluted with air through a valve before it enters the carbonatation-tanks.

SUPPLEMENT.

Sulphurous acid, which is also used similarly to carbonic acid in the carbonatation process, is either produced by burning sulphur in appropriately constructed ovens or it is purchased in a liquid state contained in iron cylinders.

Liquid sulphurous acid is somewhat more expensive to buy than it is to make the gas at the factory, although in some respects it is rather more satisfactory, especially when not very much of it is to be used and it is desired to carefully regulate the amount. If a stream of cold water is allowed to flow over the cylinder containing the liquid sulphurous acid the water will then impart to the sulphurous acid sufficient heat to convert it into the gaseous condition. The sulphurous acid thus always has about the same temperature and pressure, being at 15° to 20° (59°–68° F.), about three atmospheres (45 lbs.); and so opening the valve introduces a uniform amount into the juice. In order to prevent any of the juice getting into the sulphurous-acid container when it becomes empty, and consequently exerts no more pressure, a check-valve is placed in the piping.

Sulphurous-acid gas produced by burning of sulphur varies greatly in its percentage composition, according to the completeness

with which the burning of the sulphur has been accomplished, so that more attention is required in using this gas in the carbonation-tanks. The **sulphur-burners** must be arranged so that there is no danger to workmen in charging the burner, and so that no sulphur will sublime into the pipes and possibly get into the juices; in the one case the pipes are likely to become choked, while in the other the quality of the juices in injuriously effected. These burners are built in various ways according as the air is pumped in or the gases sucked out. In the first arrangement the burners are closed air-tight and fitted with a cooling-jacket. The air necessary for the burning is forced in by pumps, or, less advisable by steam siphons, these being regulated according to the supply of sulphurous acid desired.

When the gases are sucked, the juice itself is used as the means by being drawn continually out of the bottom of the collecting tank by a centrifugal pump and pumped back again to the tank through a jet apparatus, this latter by the action of the juice stream sucking the gases out of the sulphur-burner. Such burners are very simple affairs, iron boxes open at one end where the sulphur is burnt in a pan. Special cooling arrangements are unnecessary, since the air draught can be in excess and do the cooling.

CHAPTER XXV.

HEAT-LOSSES DURING THE PROCESS.

PROPER conditions for determining an exact **heat-balance** are lacking in the sugar-factory, and it is hardly to be expected that it would be possible to establish such under the variable prevailing conditions. At the same time it is of great importance to be able to draw some conclusion as to the amount of unused heat relative to the total generated in the boilers, for in a sugar-factory steam is used more as a vehicle of transporting heat rather than for production of power. The amount of heat utilized for mechanical work amounts to only about one or two per cent. of that contained in the amount of steam produced; after deducting this amount, which accomplishes work, the heating-value of the coal burned under the boilers must be found in the heat that escapes from the factory or is given up during the process, for there is no heat-loss in the different heating- and evaporating-apparatus, except in so far as it is lost with regard to its utilization in the factory.

These heat-losses may be of three kinds:

1. Heat-losses in the boiler-house.

2. Heat-losses in the steam while on its way from the boilers to the place where it is condensed.

3. Other heat-losses.

The balancing of the heat can only be carried out in the first two cases with any degree of accuracy.

Heat-losses in the Boiler-house.—An amount of heat is produced corresponding to from 60 to 75 per cent. of the caloric value of the coal, the balance being lost in the flue-gases and by radiation.

The heat-losses which take place here can be ascertained with accuracy according to the well-known methods.

Heat-losses in the Steam.—The steam produced in the boilers is sent partly directly and partly through the steam-cylinders of the engine to the different apparatus where it is to find further utilization. On the way, there are two sources of heat-losses: those due to radiation and heat given up to the walls of the steam-pipes, and heat which accomplishes work in the engines.

The amount of heat lost by **cooling in the steam-pipes** depends upon a number of different factors, but principally upon the length of piping and the difference in temperature between the steam and the outer air. These losses are lessened by shortening the piping and simplifying it as much as possible, and by covering the pipes with some good non-conducting material. Superheating the steam also acts favorably in this respect; for superheated steam, although the difference in temperature between it and the outer air is greater, gives up less heat to the walls of the pipes than ordinary wet steam. Superheated steam, as long as it remains superheated, behaves like hot air and is a poor conductor of heat.

In the **cylinders of the steam-engines** which are partly uncovered, there is more heat lost per unit of surface than in well-covered pipes. The continuous whirling motion of the steam in the cylinders also tends to increase the heat-losses.

The heat used up in accomplishing external mechanical work in the engines, and not for the power strictly speaking, but rather for the overcoming of friction, can be calculated from the heat laws, for 424 meter-kilograms require one unit of heat. For the production of one horse-power about 1.18 kilograms of steam are condensed in the steam-cylinders during one hour, and an amount of heat corresponding to this is taken from the steam.

Besides this mechanical work, the steam does other work, chiefly in expanding on entering the steam-cylinders, upon the pressure side of the piston, and on its exit upon the change of stroke. There is no heat-loss, however, in accomplishing this work, for the amount of heat which does work at one place is in another transformed into heat again. *After deducting the amount*

of heat lost by cooling and by mechanical work, all the rest of the heat which enters the steam-cylinder is carried in the exhaust steam.

It has been established by means of experiment that, in factories where there are a considerable number of engines and the piping is correspondingly long, there is about 15 per cent. of the heat, in the steam which passes through the engines, either lost or utilized. Of this amount 3½ per cent. is required to accomplish work, 2 per cent is lost by cooling in the steam-cylinders, and the remaining 10 per cent or so is lost by cooling in the direct and exhaust steam-pipes.

The heat-losses in the steam, which is directly transported to the place where it is to be used for heating, are naturally much smaller than the above; for this steam only suffers cooling losses in the direct-steam piping, which is shorter than in the other case. This can be estimated as 5 per cent. of the heat contained in this steam.

If it be assumed that half of the boiler-steam passes through the engines when ordinary high-pressure engines are used, and the other half is carried directly to the evaporating-pans, etc., the amount of heat lost in the steam, on its way to the place where it is going to be utilized, is about 10 per cent. of the heat taken up in the boiler, assuming the case of a factory arranged in the usual manner with a considerable network of piping.

In order to **diminish this high heat-loss,** a number of different expedients have been tried, but in all cases a careful investigation should be made as to whether there is any gain accomplished, and whether it is a pecuniary gain.

The most frequent expedient is to replace the ordinary high-pressure engines with **modern expansion engines.** From the explanation given above, it is evident that such a change, unless accompanied by other changes, cannot of itself accomplish any diminution in the heat-losses, because the amount of work done in each engine must be the same and equal quantities of heat will be used up. There is an advantage to be gained in the in-

stallation of modern engines only when the cooling-losses are diminished. This can be accomplished by shortening and simplifying the piping as much as possible, and replacing several small engines by one large one. Whether it is economical to make such **centralization of the engine work** depends upon the conditions in the factory. In equipping a new factory, it is to be expected that there will be a certain amount of centralization, at least with engines having up-to-date expansion fittings, in order to make as short and simple a system of piping as possible. On the other hand, it is not advisable to use a single engine for all the machinery and pumps, transmitting the power by belts or electricity, not only on account of increased expense, but also because, in case anything happens to this one engine, the whole work of the factory will be interrupted.

In fact, **certainty of keeping the house working** is one of the chief considerations in the conduct of a sugar-factory. Every disturbance causing temporary stopping of work will always result in increasing expense and lengthening the campaign, as well as a certain amount of sugar-losses. A factory whose machinery is not perfect, but is such that the work goes on uninterruptedly with all engines and apparatus working, will always give better results in the long run than one more modern, but which cannot be utilized to the best economy on account of causing stoppages.

In factories already constructed, it is not advisable to replace old machinery, that is capable of doing steady work, by new machinery, except when there is too much exhaust steam, and this steam cannot be utilized to advantage for evaporating. In such cases there should be a certain amount of centralization by replacing several of the older engines by a larger and more modern one, and by operating as many pumps as possible by one steam cylinder. Above all else, however, the attempt should be made to lessen the consumption of steam by adjusting the old engines and keeping them in as good repair as the better types, the valve

surfaces being well ground, the eccentrics properly adjusted, the piston made tight, and the engine tested from time to time by an indicator.

As has been shown above, relatively large amounts of exhaust steam can be used to advantage in the evaporation of juice if it is properly connected with the heating and evaporating apparatus, provided the exhaust has a pressure of about three-fourths of an atmosphere (10–12 lbs.). In factories in which there is a large amount of this exhaust, it is sometimes preferable to use a triple effect rather than a quadruple effect, if the exhaust steam only is used for heating and boiling; at all events it is possible, without going to much expense, to arrange so that the consumption of coal will be kept within reasonable limits.

It must always be borne in mind that changing the equipment at one part of the factory will usually make it necessary to make some changes in the other parts as a necessary consequence, if best results are to be obtained. Thus, when there is a centralization of the engine work it is usually necessary to change the conditions in the boiler-house, and, in consequence of the considerable lessening of the amount of exhaust, it is necessary to make some changes at the evaporating-pans, so that the cost of installation of the new engine is increased to a considerable extent.

It is almost self-evident that it is not only unsuitable, but a waste of money, to connect expansion and compound *engines with condensers* in a sugar-factory; for in such engines none of the heat can then be utilized for evaporation purposes, so that heat-losses are very much greater than in the old and ordinary sorts of engines.

The use of **superheated steam** for driving the engines, although it has been used to great advantage in other industries, and produces an equal amount of work with less steam, is in this respect less useful for the sugar-factory, except under particular conditions, namely, when the exhaust steam is present in too great a quantity, and must be diminished in amount. But, since there is never an excess of exhaust steam in a modern sugar-factory, it follows that

the superheating, as a means for economizing steam in the production of power, has no utility in the sugar-factory.

It is unquestionable, however, that the superheating of the steam is, as has already been shown, of considerable practical importance in lessening condensation losses in pipes and steam-cylinders. The greatest advantage, then, is to be gained when the heat of the waste gases from the boiler are used for this superheating; their usual temperature of 250° to 300° C. (475° to 565° F.) is too low to accomplish much superheating. This has led to use of special superheating apparatus behind the boiler tubes, where the gases have a temperature of 500°–600° (900°–1100° F.), or to heat the steam directly. Of course, in such cases heat is withdrawn from the boilers or from the fuel directly, and their evaporation efficiency is lowered somewhat. The advantage of superheating is greater in proportion as the steam is wet as it comes from the boilers in condition for revaporizing. Superheaters are advisable particularly for boilers for which great claims are made.

Up to the present time, there are no figures available to show the advantage to be gained in superheating steam to prevent cooling losses. The need of such figures is very apparent, because the expense of installing such superheating arrangements is no small matter. Further, it should not be forgotten that, during the long season when the factory is not working, the superheating apparatus will suffer more from rust than the steam-boilers and tend to become leaky. Consequently the cost of repairs must, in the course of time, amount to considerable.

With regard to the working of the engines themselves, the use of superheated steam offers certain disavantages as well as advantages which should be considered. The steam-cylinders must be much more strongly lubricated, and with a viscous and more expensive oil, than when wet steam is used, in which the water aids in the lubrication. Finally, the older types of engines are not suited for the use of superheated steam.

It might be mentioned again that it is only steam used for the

engines, and not that used in the vacuum-pans, etc., that can be superheated.

Other Heat-losses.—The heat contained in the steam or other medium carrying heat (hot water, juice) can only be utilized when it has a sufficiently high temperature.

Every time heat is utilized, or, in other words, in every transference of heat from one medium to another, there is a lowering of temperature, and the repeated utilization in the multiple effects consists only in properly distributing this fall in temperature. When a certain lower limit of temperature is reached, it is no longer possible to practically utilize the heat energy; in the sugar-factory this temperature is 70° C. (158° F.) for the evaporation and 50° to 60° C. (122°–140° F.) for heating. In the last case only a very small portion of the heat can be utilized, and only juices and water which are at lower temperatures can be heated, and such are at hand only in limited amounts.

Whether it is advantageous or practical to use heat at a lower temperature, in engines using cold steam for the production of power, seems at present to be questionable.

All the heat which has reached the lower temperature can, therefore, be regarded as useful only for heating purposes. This heat is found in the waste waters and waste products of the factory, and the amount of this heat can be estimated sufficiently accurately, because the temperature and weights of these products are easy to determine.

The amount of heat which is lost during the cooling in the different apparatus, pans, tanks, piping, juices, water, etc., cannot be estimated directly, and especially that portion of the heat energy which is contained in the vapors that escape during carbonatation, the boiling-down of the juice, the steaming-out of the apparatus and centrifugals, and by leakage.

An approximate calculation (see Appendix II) is obtained by considering that of the amount of heat which remains after deducting the heat-losses in the steam-pipes and engines; about two-thirds is lost in the waste products from the diffusers and

filter-presses, and in the excess of condensed steam, while the remaining third is lost in amounts which cannot be determined directly.

The importance of diminishing losses by cooling, and losses due to escape of steam, becomes clear from this last statement, and in it is the key to economy in the use of steam.

CHAPTER XXVI.

FACTORY CONTROL AND DETERMINATION OF SUGAR-LOSSES.

It is not in the province of this book to detail the principles and methods of chemical analysis as applied to factory control, but the statement cannot be made too emphatic that **properly conducted chemical control** is unquestionably a prime requisite for the correct and profitable conduct of the work of a sugar-factory. Unfortunately, such control is still lacking in many factories, where, it is true, in daytime the testing is more or less thorough, but at night the chemist is away, and often not even average samples are taken by which he can inform himself of the work of the night.

If it is conceded that it is unquestionable that chemical control is necessary, it does not follow that it is the sole dependence of the manufacturer. The experienced practical man at once detects anything wrong in the factory by the behavior and appearance of the juice and other products, and by many other signs, what chemical investigation shows but tardily. Such practised observation must always characterize the man who has supervision of the factory routine. No irregularity or mistakes in working with liquors or apparatus escapes the vigilance of an experienced technical man. Almost always there are many obvious tokens which indicate abnormal work, and always some of these are at once apparent to the superintendent. The results of chemical control depend much on the accuracy of the sampling, and it can happen that the chemist discovers an irregularity which actually does not occur in the work, being only in existence in a faulty sample. On the other hand, grave mistakes in the factory quite escape chemical detection if no sample was taken at such particular times, especially when no

systematic average sample is collected. Mistakes can also be made in special analyses, but it is seldom that they give occasion for any considerable error.

The field of activity for the chemist of a factory is, therefore, only covered to a small extent by the narrow confines of the laboratory; so far as he has any time available he should be in the factory seeing the general samples taken, and make it a point to test no sample if not convinced by his own observation that it was properly taken.

Superintendents and chemists, when their offices are not united in one person, should work hand in hand. Any unusual happening in the factory routine must be at once explained by chemical investigation. Chemical control and analyses are, it is true, for the special purpose of finding out factory mistakes, but their chief value is *to determine the magnitude of the error* and the *means for its abolishment.*

Laboratory tests which are designed to **show what the factory is doing or to explain factory troubles** must be well planned out and conducted with every care, and, above all, under conditions imitating as closely as possible those actually existing in the factory. Otherwise the results are useless for practical application and indeed positively mischievous, as they lead to false conclusions. Many ideas which are foreign and out of date, and even some that are passed around by practical men and kept alive from generation to generation, owe their origin to investigations erroneously carried out or to those from which erroneous conclusions have been drawn. Often, it should be observed, investigations made with beets of inferior quality, or by analytical methods no longer recognized as exact, have been used, and hence for the conditions existing to-day they have no scientific value, just as the conditions as known to-day may have as little relation to those which may control the industry of the future.

It is quite wrong to attribute factory troubles to the quality of the beets without investigating further. It is indeed true that beets of different campaigns and at different periods in the same campaign are apt to work up differently, but by making a few

common-sense changes in methods to suit the conditions, almost any beets which are not obviously rotten or frozen or do not show extraordinary damage will work up well, or at least work up so that the factory can run to its full capacity. In very many cases blame for factory troubles can in nowise be laid to the beets, but to some other cause, which will be detected quicker if the habit is broken of attributing everything to the beets. At the beginning of the campaign particularly, troubles occur which are not caused by unripe or damaged beets, but by mistakes of inexperienced workmen, such as are at first not readily detected by superintendents till they themselves again get in practice and work back into the fine points of routine.

Chemical control of the sugar-factory has its chief value in the **determination of sugar-losses.**

The difference between the amount of sugar in the beets as shown by polarization and that in the massecuite or in the sugar obtained as a commercial product is the total sugar-loss in manufacture. If the determination of weights and polarizations have been worked out correctly the **total loss** is usually higher than the sum of those losses which can be determined in waste-products, and in wash- and condensation waters. A distinction is therefore made between *determined* and *undetermined* losses, or, to put it better, between **known** and **unknown losses.**

To determine the amount of sugar going into the factory the beets must be accurately weighed and their sugar-content determined in good average representative samples. In countries where the excise-tax laws do not compel the beets to be weighed it is often deemed sufficient to obtain this weight indirectly from the number of diffusion-cells filled, or by a calculation based on the weight of the diffusion-juice and the sugar-content of beets, diffusion-juice, and waste-products. By this last method the assumption is made that the undetermined losses do not occur during juice-extraction, so that the sugar obtained in the juice, together with that determined in the waste-products, represents the sugar-content of the beets. No great accuracy can be claimed for this way of calculating, and it is a matter of surprise, when the great value of chemical

control of the sugar-industry is recognized, that the slight expense is not incurred to meet the first and most important requirement for such control.

Only those methods for the determination of the sugar-content of the beet-slices known to be accurate can be used, namely, alcoholic extraction, which must be controlled by extracting a second time, or the hot-water-digestion method properly carried out. Although by these methods not the sucrose-content but the amount of polarizing substances is given, this test will be regarded as scientifically correct till it becomes possible to separate the sucrose from the other optically active substances. Especially to be rejected are those methods which, designedly or not, are conducted with less care and so give lower figures, which, while possibly agreeing better with the results of factory practice, are nevertheless false.

Since by the new processes of working up massecuites there are no longer any pure first-product massecuites, the sugar obtained must be determined from the weight of the first-sugar product and the volume of the second massecuite, or, if this is also worked up with a grain foundation of added sugar, from the weight of the finished commerical sugar and the molasses. The more the sirups are worked up during the campaign the greater the difficulty in separating them to reckon the weekly yield. Nevertheless, some kind of a separation of sirups can be worked out, and at least several times during the campaign a determination of yields and losses should be made with as great accuracy as possible. Small amounts of sirup which are carried over in the account from week to week can be reckoned as massecuite. There is no difficulty in taking average samples of sugar or sirup massecuites.

The only **determinable sugar-losses** are those occuring in the filter-press scums in the diffusion work and the loss in the condenser water, for these are the only losses capable of measurement and which can be calculated with reasonable accuracy from tests of the waste-products. There are other losses of which we have positive knowledge, but whose magnitude cannot be quantitatively measured through lack of all data, and which, therefore, have to be reckoned as undeterminable.

To this class of undetermined losses, which are *recognized, but which do not last long enough at one time to permit of quantitative determination,* belong especially those losses which are due to decomposition of sugar in evaporating and boiling, losses in the filter-press cloths, and mechanical losses caused by entrainment of juice or sirup. All these losses taken together do not, however, reach a figure of much magnitude, and at most are reckoned as a few hundredths of a per cent. on the weight of the beets, assuming of course that the juices are normal and are worked up alkaline, and that no mechanical loss out of the ordinary has occurred. Hence these losses give no explanation of the considerable amount of undetermined loss which occurs in every factory, and is always found however careful the chemical control. The greatest vigilance and care are necessary in determining the known losses accurately. If the tests are made carelessly, whether in sample taking or in analysis, the losses found, both total and known, are almost invariably too small. If the books show a small sugar-loss it is not by any means evidence of good work. On the contrary, such figures should be viewed with some suspicion.

As is well known, according to the annual reports of factories whose technical standing is recognized as good, the total sugar-loss is given as 1.0–1.5 per cent. of the beets, of which 0.5–0.7 per cent. are known losses, so that a half more appear as unknown losses, and so far cannot be explained as being losses recognized but undetermined. While it is unpleasant for a superintendent to contemplate losses as great as these, which would be serious if they actually did represent sugar, it certainly is still more unsatisfactory to one who wishes to get at the truth of practical sugar work. It is, however, almost certain that these "losses" are not sugar-losses, but *errors of polarization,* although so far no satisfactory explanation has been given to account for them.

The *sugar-losses* which are worth consideration are only those which have been actually determined, and it may be better in some ways to report only these, as their measurement is what concerns the technical man. The total loss determination, on the contrary,

gives utterly erroneous ideas of the actual work, and may be looked upon as of no value.

The most important **known sugar-losses** occur in the **diffusion work,** especially in the exhausted slices and waste-water. It is very difficult to collect a proper average sample of the exhausted slices, for not only do the different tanks have residues at different degrees of exhaustion, but slices in the same diffuser vary much in their sugar-content. Further, as the weight of the wet slices is not determined directly, and the adhering water varies from 80 to 100 per cent., determinations should be made on these slices merely for control of the diffusion, the sugar-loss being calculated from tests on the *pressed residues* and on the *press-water.* The weight of the pressed residues can be determined exactly from the accounts of the farmers. Good average samples can be obtained at the bins below or in other ways. These are always more reliable than those taken on the wet slices, as this residue has been thoroughly mixed in passing through the various conveying machinery, such as bucket and screw elevators, as well as in the presses themselves. The determination is best made by the hot-digestion method, which gives very satisfactory values for this waste product, which is the richest of all in sugar. Obviously, good average samples of the press water can be obtained very easily, especially if some kind of dropping-apparatus is used for taking samples. The weight of the press-water, which will hardly exceed 10 per cent. on the beets can only be estimated, but, as its sugar-content is relatively small, the error is of no consequence. The same remarks apply to the diffuser *waste-waters,* whose amount can only be estimated if extra water is used in discharging the chips. The sugar-content in these waters is, however, still less than in the press-waters, so that an exact determination of the amount of water is of no consequence, since the greatest error which would be introduced would only affect the loss determination a few hundredths of a per cent. on the weight of the beets. In diffusion where the waste-waters are worked back and in the hot mash methods there is obviously no sugar loss if the sugar collected in the dry by-product is reckoned as recovered. In these processes care need only be

taken that the fodder contains only so much sugar as is profitable.

It is not easy to take good average samples of **carbonatation-scums,** as the press-cake of different filter-presses, and, indeed, of the same press, show very different degrees of sweetening off. Samples should be collected when the press is discharged by taking portions of several cakes and from different places in the cake. The surer method is to sample from the scum-wagons by means of a trier. When the scums are disposed of by mixing with water to a thin paste very good average samples can be collected easily, but, of course, the sugar must be calculated on the weight of the original scum, which requires a determination of the water-content or the specific gravity of the watery mixture. The weight of the scums is usually determined from the number of presses which have been discharged. It suffices, however, to calculate the scums from the weight of lime used, as they can be taken as 3.5 to 4 times the weight of the latter, accordingly as they are dry or wet.

Suitable samples can be collected from the **hot-well waters** of the condensers by means of accurate drop-sampling apparatus. The amount of water can be calculated with sufficient exactness, if its temperature is known, as well as that of the condensed vapors and the injection-water.

The **calculated factory losses** per 100 parts of beets, in a factory using ordinary diffusion, are about as follows:

Total sugar-loss..				1.20% of beets
Of which are known				
In expressed beet residues	50%,	polarizing	0.50%	=0.25%
Press-water...........	40%	"	0.20%	=0.08%
Diffusion waste-waters	130%	"	0.10%	=0.13%
Scums, 1st carbonatation	8%	"	1.5%	=0.12%
Scums, final "	0.5%	"	4.0%	=0.02%
Hot-well water........	600%	"	0.00	=0.00
Total known losses..				0.60%
Unknown losses..				0.60%

In factories where the diffusion-juice is exactly measured the **total losses in juice extraction** can be exactly determined if correct average samples are collected. As this juice always contains

many germs which quickly decompose sugar the samples must never stand more than a half hour, or at the very most an hour, without addition of lead acetate or mercuric chloride. Whether the diffusion process is responsible for greater losses not yet capable of determination is a much-discussed question, which has not yet been answered. In the pressing, as in the diffusion as carried out in the usual manner nowadays, the sugar brought in in the beets will be found again in raw juice, waste-waters and fodders. Nevertheless, the sugar which is contained in the raw juice, after making deduction for losses calculated for scums and waste waters will not be found exactly in the massecuite. As has already been stated, what is the cause of this undetermined loss, which amounts to about ½ per cent. on the weight of the beets, is not at all clear.

Among the losses not capable of determination are especially those known as **mechanical losses,** caused by leaks in valves or heating-coils, as well as those due to carelessness of workmen. It is the business of the practical factory man to prevent these as far as possible. Discharge-valves which are leaky or not properly closed are the cause of juice-losses in the diffusion. Such discharge-valves should be done away with where the spurting of water from the lower manholes on opening the diffusers can be prevented, as is possible with side discharge by use of cloths. The space under the sieves should be filled with hydraulic cement, leaving only room enough for the flow of juice between the sieve and the bottom, or otherwise considerable cold water collects there and later on dilutes the juice when the diffuser is filled with fresh slices for mashing. As a rule the later forms of diffusion-plants have discharge-valves and manholes in plain view, so that any leak would be at once detected and loss prevented. Mechanical juice-losses can also occur at the waste-valves of carbonatation-tanks and evaporators which are used for washing out on Sundays. Such valves or cocks should always be closed by the superintendent or his representative personally, and locked to prevent any improper use. It is hardly necessary to say that all waste-pipes and likewise all juice-pipes should be so placed that they can be easily inspected.

Losses by leaks of heating-tubes or -coils in evaporators or

vacuum-pans ought not to escape notice, since the greater part of the condensed water is utilized for boiler-feed, and the smallest amount of sugar makes itself noticeable by the odor of the steam. Condensed water not used for boiler-feed, especially that from the juice-heaters, should be frequently tested for sugar.

If these simple precepts are followed no mechanical loss can take place without being detected.

CHAPTER XXVII.

GENERAL SUGGESTIONS CONCERNING THE EQUIPMENT AND MAINTENANCE OF A BEET-SUGAR FACTORY.

A BEET-SUGAR factory is one which prepares from a natural raw product a product still crude but greatly improved. It is only in special factories, or special parts of the same factory, that this crude product is made over into a product ready for use. There is, therefore, no reason for aiming at any beauty in buildings or machinery, as is to some extent necessary in factories built for advertising purposes. The chief requisite is the **practicability of the arrangement as a whole** and the individual parts, as well as **economy.** Attractiveness, such as a beautiful arrangement of the factory, or a beautiful engine-house, costs money, without aiding in the attainment of the purposes for which the factory is built, which is to produce economically from beets the greatest possible quantity of sugar of good quality; it increases cost of manufacture by raising the costs of insurance and interest. Such sums play an important part in the conduct of a beet-sugar factory in which it is necessary to make the entire year's earnings within a few months.

With regard to the fittings and method of working the factory much depends upon the **customs** levied and the **demands of commerce.** In countries in which there is a tax upon the weight of the beets it is necessary to avoid as much as possible all losses at the different stages in the manufacture, because the value of the sugar is greatly increased by this duty, sometimes giving it double its original value or more. In such cases the number of diffusers and filter-presses should be large. On the other hand, when there is a

tax levied upon the juice it is not so important to exhaust the beet-chips thoroughly, but more stress is to be laid upon the production of a juice whose temperature and purity are most favorable when the duty is considered. It is also necessary in this case to carefully sweeten off the scums and to avoid all losses caused by the mechanical entrainment of sugar with the steam, but these are always the aims of the sugar-manufacturer in every sugar-factory. In countries where there is a sugar-tax levied upon the finished product the factory cares less for sugar-losses during process of manufacture. Of course the sugar-losses should on no account exceed a reasonable amount, but frequently it is better to work rapidly, and prepare a good product rather than to make the yield greater and the product poorer.

The demands of commerce, or, in other words, the market, regulates the quality of the sugar produced, and this has its influence upon the conduct of the sugar-house. When an alkaline product is desired by the trade it is necessary to regulate the process in this respect from the defecation onward.

A good beet-sugar factory should have well-ventilated, well-lighted and spacious rooms arranged so that the workings of the whole factory can be easily watched by the one in charge. The requisite cleanliness should be easily attained and the machinery and apparatus should be good, strong, and conveniently arranged. As to whether engines and apparatus should be of the latest pattern and design is a matter of more or less indifference to the practical sugar-man. If the engines furnish the requisite power without an excess of steam in the exhaust, and all of the apparatus is properly arranged and capable of doing the work expected, they fulfil their purpose, and it is entirely superfluous to make any other demands in this respect. The duties of the manager of the factory cover all the details involved in the manufacture of the sugar, and he must observe everything that happens to the beets or to the juices, suggesting improvements when necessary. This takes up pretty much all of one man's time, so that the care and working of the engines and machinery should be left to the engineer. All irregularities in the working of the engines or machinery which

may cause trouble in the process should be looked after at once, for *preventing stoppages*, together with *working the factory up to its capacity*, are the chief factors towards working cheaply and well. Each stoppage involves expense, not only on account of the unemployed labor and waste of fuel, but also because the purity of the juice is lowered and sugar-losses are greater in the beets that are stored for a longer time.

The more rapidly juices are worked up, by avoiding all stoppages, the better their quality. They suffer especially in slow diffusion, by delays in carbonatating, in evaporating and excessively by prolonged boiling in vacuum pans. Their worst characteristics show in stickiness and dark color in massecuites, in poor yield and difficult purging. It is always wrong to have apparatus too large at any stage of the process. When this is the case, either the apparatus in question must be reduced in size, or the other apparatus increased in proportion, so that the capacity of the factory will be changed. When the size of the apparatus at any point is increased care must be taken to make sure that the new capacity corresponds to that of the apparatus at the other stages of the process, as otherwise it will be necessary to make certain changes or enlargements annually. The size of different forms of apparatus should be such that those later in the process have a slightly greater capacity than the preceding, or at least it should be possible to make the increase quickly. This is particularly true of any transporting-apparatus which takes product from another. Indeed, transporting and transmission machinery can never be made strong enough; this statement ought to be made most emphatic as unfortunately grievous sins are too often committed on this point. A fourfold factor of safety should be demanded over that required for transporting apparatus in other industries for equal loads, especially for beet and chip carriers, owing to the exceedingly variable conditions of their use and because frequently, when the work is pushed, they do not come up to the capacity shown previously.

Increasing the size of the factory is usually the best way to reduce the cost of manufacture, but this is true only within certain

limits. If a factory can obtain all the beets needed so as to maintain a campaign of a normal duration, increasing the capacity of the factory should stop only when the freight charges for bringing beets from a distance more than compensates any gain in the economy of operating the factory. It may then be more advantageous to build a new factory in a more central location. If a factory cannot obtain more beets than are used at present, increasing the size of the factory will result simply in shortening the campaign. This is advantageous up to a certain extent, because the cost of operating will be somewhat diminished, and it will not be necessary to store beets at all, since they can all be worked up at the time of their greatest sugar-content. If the duration of the campaign has been reduced to about six weeks then increasing the capacity of factory will be not only unnecessary but even injurious, because it may happen that the farmers cannot supply the beets fast enough in the shorter period, and, consequently, the work may have to be stopped on account of their insufficiency. In such cases it is better to attempt to improve the process and to increase the yield by careful work rather than to enlarge the factory.

When **new appliances are added for improving process** the gain should be quite considerable. In most cases the returns should show interest upon the capital invested of from 15 to 20 per cent., because every year new discoveries are being made which make the apparatus at hand become more or less out of date, so that its value decreases rapidly. Furthermore, many innovations correspond to the prevailing fashion in the manufacture of apparatus or the price may be set altogether too high by advertising. At one time a number of improvements will be suggested with regard to the diffusion, at another time it will be the defecation that is improved, and so on throughout the whole process, as a result of fashion to some extent. Those who attempt to follow all these changes will soon empty their purses without effecting any corresponding gain. Consequently one should go slow, as more harm is usually done by changing too quickly, and frequently the actual advantages to be obtained from an invention may be attained in a

much more simple manner. If, however, the advantages of a new device are apparent no time should be lost in adopting it.

For careful. work great **cleanliness** should be maintained throughout the whole factory, but, above all else, the work itself and the inside of apparatus should be clean. Although it is advisable to keep the whole factory clean it is not wise to pay too much attention to exteriors, for it is in the different vessels where the juice is contained that cleanliness is of most vital importance. Those which otherwise require little attention continually demand care in this regard.

The **total cost of operating** a factory is naturally very different in different cases. On the other hand, the actual expenses incurred during the campaign are only slightly different in the various factories. In German factories the expense during a campaign was found to be per 100 lbs. of beets: wages, 1.15 c. to 1.36 c.; fuel, 0.9 c. to 1.15 c.; lime, 0.11 c. to 0.34 c.; press-cloths, 0.45 c. to 0.57 c.; and lubricants, 0.45 c. to 0.57 c. The greater the number of beets worked up into sugar the smaller becomes the cost of each pound of sugar produced. In Germany it costs from six to ten cents to work up 100 lbs. of beets, allowance being made for depreciation in the value of the plant, repairs, summer work, etc. It is always hard to estimate correctly the cost of manufacturing sugar, for sometimes small factories work more economically than large ones, particularly when the freight on beets and by-products is taken into consideration.

For practical control of the factory it is well to place the data of the working at each part of the factory upon a blackboard, or upon a chart, so that a very good idea of just what the factory is doing may be obtained by simply inspecting these items. In such cases the following details should be noted: The amount of beets used, the number of diffusers filled, the length of time each diffuser is in operation and the time of discharging, the degree Brix of the diffuser-juice from each measuring-tank, the number of emptied presses, the number of defecating- and carbonatating-pans in operation, the density of the thick juice that is drawn off, the alkalinity of the juices, the beginning and end of each boiling, both of firsts

and after-products, the time of stirring and temperature in the crystallizers, the number and contents of the vessels containing the after-massecuites, the weight of the centrifugated sugar, and, furthermore, the data concerning the operation of the boiler-house. Noting all these details helps greatly in the rapid detection of mistakes and troubles in process.

At the same time the real day-book or **journal of the factory** should not be forgotten. This should contain all technical data, not alone notes taken from the factory working and extracts from the laboratory book, but also the receipts of fuel, limestone, lime, filter-cloths, acid, lubricants, etc., and the sugar-sacks, the amount of beets received and the quantity stored, as well as the storage, delivery, and examination of the sugar. These results are all the more valuable if the notes are taken neatly and arranged so that the data are easy to find. It is not easy to give a scheme for tabulating the results in such a book, because the conditions vary so much in the different factories.

In some factories **samples** of juices, massecuites, etc., are taken at regular intervals, and the results are shown to the superintendent of the factory. Although this practice is, on the whole, very commendable, the results are sometimes misleading on account of workmen always taking favorable samples. It is well to take the specimens personally when possible, and not leave it to workmen.

A very important, although less busy, period is the **time for making repairs**. After the beets have all been worked up the machinery and apparatus should be cleaned immediately, at first somewhat superficially, and later very thoroughly, and everything should be closely examined to see what repairs are necessary. The heavier repairs which will have to be made in a machine-shop should be made early in the spring, for the mechanics are then not very busy and the work is more likely to be done carefully and finished on time.

Such repairs and minor improvements as can be carried out at the sugar-house should be divided proportionately through the whole of the period that the factory is idle, so that workmen are uniformly

busy throughout the whole of the summer. Of course, it is advantageous to be as independent as possible, and it is best for the factory to make all the repairs it can on the spot.

The parts, after being inspected and repaired, are immediately put together again. They should be kept dry and covered with grease to prevent rust, and they should also be protected from dust by suitable coverings.

In case of doubt as to whether repairs or new parts are necessary it is always well to consider what the effect will be if the part gives out during the campaign: does the whole factory-work depend upon the piece of machinery in question, or can the repairs be made during the campaign without stopping the regular work? The engines and apparatus upon which the progress of the whole work depends must always be in perfect condition, and this is especially true of all parts which are hard to get at. Careful attention to repairs and proper setting up of machinery tend greatly to prevent disturbances and accidents during the working period.

Not only should the boilers be tested to see that they are tight and capable of standing pressure, but the evaporating-, boiling-, and heating-apparatus should be carefully examined to see if they are in good shape for another campaign. Heating-coils which are to be heated with direct steam from the boilers should be tested with a water-pressure which is at least one or two atmospheres higher than the greatest steam-pressure to which they are likely to be subjected. With the apparatus which is heated with low-pressure steam the water-pressure from the tanks is usually sufficient if it has about one atmosphere overpressure (15 lbs.). In carrying out these tests the different cocks connected with the different forms of apparatus should be set in their proper position. It is advisable to test not only the heating-spaces but also the boiling-space of evaporating-apparatus with water-pressure, after it has been boiled out with acid.

All heating-tubes and steam-coils must, of course, be freed from any scale that has deposited upon them. The mineral deposits must also be carefully removed from the condensers, defecating-,

and carbonatation-pans, and all of the piping through which juice passes.

All of the valves and cocks should be taken apart and examined, discs and seats well ground, and any imperfect washers of rubber or vulcanized fibre renewed, particularly in the valves of the diffusers, carbonatation-apparatus, filter-presses, and exhaust-steam and vapor lines.

In localities where frost can penetrate into the factory after the close of the campaign, the steam cylinders, piping, and valves must be disconnected and left open so that they will always be free from water; otherwise ice may form in the pipes, perhaps causing them to burst.

When it is customary to keep the different pipes well painted it is well to use different colors, so as to show which liquid flows through them.

Before beginning work with the beets, all of the machinery, the different apparatus and piping, etc., should be tested, at first separately and then a test is made with water, in which all of the operations are carried out that the juices are to undergo. If everything is then found to be in satisfactory working condition it is reasonable to expect that there will be little trouble at the beginning of the campaign.

CHAPTER XXVIII.

THE UTILIZATION AND DISPOSAL OF THE WASTE-PRODUCTS AND SWEET-WATERS.

Of the different waste-products in a beet-sugar factory the following are worthy of consideration: the press-cake or carbonation-scums from the filter-presses, the beet-earth from the silos and settling-tanks, and the beet-tops.

Filter-press cake (scum) is usually considered a very desirable fertilizer for the soil. Besides calcium carbonate it contains phosphoric acid, nitrogen, and potash. The percentage composition depends not only upon the amount of water present, but also upon the amount of these substances which were present in the beets, and upon the amount of lime used in the defecation. The water-content usually varies between 40 and 50 per cent. With an equal amount of water present, and under otherwise similar conditions, the highest percentage of phosphoric acid and nitrogen is obtained when the least lime is used in defecation; for when 1.75 per cent. of lime is used the same amount of phosphoric acid and nitrogen is present in 7 per cent. of the cake as will be present in 12 per cent. of the cake when 3 per cent. of lime is used. It is evident, then, that the chief cause for the varying percentage composition of the press-cake is due to different amounts of lime used in defecating. The following is an average chemical analysis of the dried scums: Phosphoric acid, 1 to 2.5 per cent.; nitrogen, 0.2 to 0.4 per cent.; potash, 0.05 to 0.3 per cent.; carbonate of lime, 55 to 75 per cent.; organic matter, 10 to 15 per cent.

The physical nature of press-cake has an important influence upon its value. As it is obtained in the factory it constitutes a hard, dirty, greasy mass which cannot be ground up easily,

and if added in this condition it lies upon the ground in larger or smaller lumps, which naturally exert no effect upon the soil. If it is kept in heaps for some time, or if it is mixed with earth and allowed to dry, it becomes brittle and is then an excellent fertilizer with a quick action. If the soil is deficient in lime it is well to mix the cake in a mixing-apparatus with powdered lime. In this way a finely powdered mass is obtained which is easily distributed over the soil and must act quickly upon it.

In some factories the press-cake is mixed with water into a paste, and this is then allowed to run into the wash-water, and becomes well mixed in the settling-tanks with the earth from the beets. In this way a very good composite earth is obtained which is often highly prized by farmers in the vicinity of the factory; it would not be economical to pay freight on it.

Cost of transportation likewise stands in the way of the practical utilization of the **soil deposited from beets** in the settling-tanks. This earth, however, makes a very good fertilizer, and it is usually easy to get rid of it without incurring expense. Mud scrapers, which often are easily constructed, as well as wheel elevators, have proved very useful for taking up the semi-liquid mud deposit and transferring it to level ground for drying. By such an arrangement any deposit space is done away with and the mud dries much quicker and is handled easier.

A valuable waste material are **beet-tails** which drop down with the water and dirt through gratings and small openings in carriers, rakes and washers, the amounts of this material depending on the quality of the beets, and the way they are unloaded, transported and washed, as well as the width of gratings and openings. The quantity usually varies from 1–2½ per cent. of the beets. The sugar contained depends on the size of the tail. the thicker ones having approximately the same as the beet, the finer ones containing only 2–4 per cent. The average sugar content can be taken as 8–10 per cent., the dry substances as 12–16 per cent.

The water from hydraulic carriers and washers is passed over *beet-tail catchers* to remove the tails. These are built like chip

catchers and have long slitted sieves which are kept clean by scrapers or brushes or are apparatus with drum sieves. Naturally, all the larger impurities of this nature in the water are likewise caught, such as leaves, weeds and stones.

The simplest use for these tails is directly as a fodder. They must be fed promptly, as they soon sour and the cattle will not eat them. Hence, as it is seldom possible to feed the tails at once, they are more conveniently mixed with the pulp residues for foddering or ensilage.

These tails could be utilized much better if chopped up and put into either the diffusers or driers. Putting them in the diffusers is most profitable, as the greater part of their sugar will be extracted in the juice, the balance going to the pressed chips.

The purity of the juice extracted from the beet-tails is of course less than from the normal beet juice, rarely reaching 80, but usually being 70–75.

Nevertheless, good massecuites are obtained after the lime purification, so that putting the beet-tails into the diffusers gives a distinctly greater sugar yield.

These beet pieces must be washed and freed from stones before they are cut up, for which small washers, built on the principle of the ordinary beet washers, serve. The cutting up is done by special machines, usually having two toothed wheels running in opposite directions, slicing machines not working on account of fibre and leaves. The cuttings are mixed with the fresh chips for diffusion, pressing and drying.

The beet-tail cuttings are somewhat less extracted in the diffusion than are the regular chips, but at least 70–80 per cent. of their sugar is extracted in the juice. The dried product represents 12–16 per cent. of the fresh beet-tails.

Beet-tops which are removed mechanically from the dirty waters are prized as fodder and paid for according to their food-value. Recently they have been cut up and either extracted with the chips or dried directly.

The **waste-waters** from the factory are always a source of more or less care and expense. The dirty waters leaving the

factory are from the hydraulic carriers, the beet-washers, and the waste-waters from diffusers and filter-presses. If the press-cake is mashed with water and pumped to settling tanks, there is this clarified water in addition. Only in exceptional cases would pure water be mixed with these waste-waters, as any excess of pure water is utilized for hydraulic carriers or recovered. The **amount of waste water** for each 100 lbs. of beets is about as follows:

From the carriers and washers......	60	to	84	gallons
From the diffusion and waste-waters.	13.2	"	18	"
From the chip presses...............	3.6	"	6	"
Other wash- and waste-waters......	0.6	"	1.2	"
Total........................	77.4	to	109.2	"

For a factory working up about 1000 tons of beets daily the amount of water used is, therefore, from 1.6 to 2.2 million gallons.

In these waste-waters the floating particles are not the most injurious, but the dissolved constituents. The solid, floating part can be removed at once by the beet-tail and pulp strainers and subsequent settling in decanting tanks of appropriate size.

It is very advantageous to treat the waste waters in separate lots, taking the hydraulic-carrier and wash-waters, which are particularly dirty, as one and the waters from the diffusion as another portion. The latter contain by far the most organic matter, about 0.15–0.30 per cent. of sugar or 1500–3000 grams in a cubic meter (12.5–25 lbs. per 1000 gals.), and practically the same amount of non-sugar of which the major part is organic. It should be remembered that this dirty sugar and organic matter comes out of the beets, the water holding at least 20–50 grams of sugar per cubic meter (.17–.42 lbs. per 1000 gals.), rising with frozen beets to 500 grams (4.2 lbs. per 1000 gals.).

Only a few factories are so fortunately situated as to have an abundant supply of pure, fresh water for all departments, and at the same time be able to discharge all the mechanically clarified

waste-waters into a large stream. In all other factories the solution of the water problem depends on whether the waste-waters must be used over again, owing to the plant being short of water' or because of the difficulty of their disposal. In either case the endeavor is to draw out as little of these waters as possible. For the purification of the unavoidable waste-waters, the aim is to convert, by fermentation or oxidation, the complicated organic substances which the water contains into their simplest or, so to speak, inorganic constituents; as, for instance, sugar into water and carbonic dioxide, nitrogenous substances into ammonia and nitrates.

The amount of waste-waters can be reduced the most by separating the diffusion waste-waters and working them back, either in the diffusers, the presses or in the scalding process.

Another way of recovery of the waste-waters is to allow the diffusion waters to ferment, without lime, in separate basins, either by themselves or after mixing with the clarified foul waters. The resulting clarified acid waters are used for general diffusion purposes and pressure water. This makes no trouble in the diffusion if the temperature of the last cell is brought up to 70°–80° C. (160°–175° F.) as quickly as possible, the resulting juice and sugar being of normal quality. Nevertheless, this method of waste-water utilization should only be looked to as a last resort as such waters contain notable amounts of injurious non-sugars which must lower the purity of liquors and massecuites. Moreover, pumps, piping and filter-press screens are injured by the strongly acid water, and often the odor of sulphuretted hydrogen is by no means a pleasant accompaniment.

Nowadays almost everyone has given up the use of chemical agents for precipitating the soluble impurities in unfermented waste-waters and for the hastening the settling. On the other hand, calcium carbonate, cheapest in the form of press scums, is known to be of much advantage both in fermented and unfermented waters, as it neutralizes the acid and the fermentation proceeds much more energetically in neutral or weakly acid solutions.

Caustic lime purifies fermented waters to a considerable extent, as it precipitates organic matter. Hence, addition of milk of lime is strongly recommended. This fermentation is carried out in wooden tanks as the ingenious apparatus used for purifying city sewage is not practicable for this purpose owing to the large amounts of unfermentable and putrefactive matter.

The fermented water which in certain instances is again purified with lime is usually put on a filter-bed, whence it comes pure as far as is possible according to the present state of our knowledge. The success of this purification depends especially on the care exercised in overseeing the different stages of process and upon having the rotting tanks and filter-beds of sufficient size.

The problem of complete purification of the waste-waters from a sugar-factory is, therefore, an unsolved one, and is probably not capable of solution. It cannot be expected that the water be completely purified, and local circumstance will decide to what extent this purification is necessary and can be carried out. Where the water can be let into a large stream simple clarification in the settling-tanks, together with the self-purification of the running water, is sufficient to make impurities uninjurious in a short time, and if small amounts of slime do run off with the water they do no harm. Moreover, the dissolved impurities through the self-purification of the stream soon become harmless. The smaller the stream the less the dilution of the waste-water, and hence the more thorough must be the purification to insure harmlessness and the greater the necessity of cutting down the waste-waters and utilizing them in process.

The waste-waters from a sugar-factory are not injurious to the health of man or beast, but when there are only small streams of running water for their disposal they may be capable of producing very disagreeable phenomena. They are not of themselves directly injurious to the fish in the streams, but this cannot be said of molds which are formed from them. In the course of time these molds may decay and in the process generate so much hydrogen-sulphide gas that all of the fish may be killed.

To determine to what extent the purification of waste-waters

should be carried out it is necessary to know the nature of the organisms developed in the stream into which they go. There are three kinds of micro-organisms which need chiefly to be considered: *leptomitus*, *sphærotilus*, and *beggiatoa*. *Leptomitus* is found in relatively pure waters, so that its formation indicates that the water has been sufficiently purified. *Sphærotilus* develops in impure water, while *beggiatoa* occurs in ill-smelling water containing putrid matter; these two latter, therefore, indicate that the water has *not* been sufficiently purified.

CHAPTER XXIX.

ANALYSIS OF BEETS, SIRUPS, AND SUGAR PRODUCTS.

The Average Composition of Juices, Sirups, Massecuites, and Sugars of a Factory for the Campaign, 1898–99.

(*a*) JUICES AND SIRUPS.

	Beets, hot water digestion.	Diffusion juice.	I. Saturation juice.	Thin juice.	Thick juice. Unsaturated.	Thick juice. Saturated.	Purged sirup. I. Prod.	Purged sirup. II. Prod.	Molasses.
Brix	—	14.4	—	12.2	—	53.3	77.4	76.4	82.8
Polarization	14.66	12.2	—	10.9	—	48.0	56.9	49.1	47.8
Apparent quotient	—	84.7	—	89.3	—	90.1	73.6	64.3	57.7
Alk. phenolphthaleïn	—	—	0.091	0.049	0.142	0.049	0.11	0.11	0.08
Alk. rosolic acid	—	—	0.11	0.067	—	0.075	—	—	—
Lime (by volume)	—	—	—	0.043	—	0.16	—	—	1.6
Invert sugar	0.17	0.18	—	—	—	—	—	—	—
Acid (ccm. normal acid) phenolphthaleïn	—	2.1	—	—	—	—	—	—	—

(*b*) MASSECUITES, SUGAR, AND MOLASSES.

	Thick juice.	Massecuites. Boiled with sirup. I.	Massecuites. II.	Massecuites. III.	Molasses.	Raw sugar. I.	Raw sugar. II.	Raw sugar. III.
Polarization	47.9	83.5	67.1	58.7	47.8	96.1	92.1	90.8
Water	47.7	7.55	10.42	11.5	21.83	1.50	2.56	2.70
Ash (SO_3)	1.72	3.48	8.52	—	11.78	0.93	2.07	2.81
Organic non-sugar	2.67	5.47	13.96	—	18.59	1.47	3.27	3.69
True purity	91.6	90.3	74.9	66.4	61.1	—	—	—
Alkal. phenolphthal.	0.039	0.064	0.12	0.14	0.08	0.011	0.035	0.030
Lime	0.12	0.27	0.62	0.76	1.6	—	—	—
For 100 polarization:								
Ash	3.6	4.1	12.7	—	24.6	—	—	—
Organic non-sugar	5.6	6.6	20.8	—	38.9	—	—	—
Lime	0.25	0.32	0.93	1.29	3.3	—	—	—
Alkalinity	0.08	0.08	0.17	0.24	0.16	—	—	—
Organic non-sugar: Ash	1.55	1.57	1.64	—	1.58	1.58	1.60	1.32

Campaign of 1902–03.

(a) juices and sirups.

	Beets, hot water digestion.	Diffusion juice.	I. Saturation juice.	Thin juice.	Thick juice. Unsaturated.	Thick juice. Saturated.	Purgings.	Molasses.
Brix	—	14.0	—	12.6	—	59.6	81.0	83.8
Polarization	14.91	12.1	—	11.5	—	55.0	60.6	49.8
Apparent quotient	—	85.5	—	91.5	—	92.3	74.9	59.4
Alkal.: Phenolphthal.	—	—	0.093	0.041	0.133	0.045	0.142	0.18
Rosolic acid	—	—	0.11	0.051	—	0.064	—	0.26
Lime (volume per cent)	—	—	—	0.035	—	0.101	—	0.60

(b) massecuites, sugar, and molasses.

	Thick juice.	Massecuites. Boiled with sirup. I.	Massecuites. II.	Molasses.	Raw sugar. I.	Raw sugar. II.
Polarization	54.9	84.7	70.4	49.7	95.15	94.0
Water	41.0	6.93	7.32	19.33	1.40	1.85
Ash (SO_3)	1.63	3.24	8.56	11.92	0.88	1.60
Organic non-sugar	2.47	5.13	13.72	19.05	1.56	2.55
True purity	93.1	91.0	75.9	61.6	97.5	95.8
Alkal. (phenolphthaleïn)	0.034	0.062	0.137	0.14	0.013	0.020
Lime	0.080	0.16	0.40	0.60	—	—
For 100 polarization:						
Ash	3.0	3.8	12.2	24.0	—	—
Organic non-sugar	4.5	6.1	19.6	38.3	—	—
Lime	0.14	0.19	0.57	1.2	—	—
Alkalinity	0.06	0.11	0.19	0.28	—	—
Organic non-sugar:						
Ash	1.52	1.60	1.61	1.60	1.77	1.62

SUMMARY

OF THE ALKALINITY (PHENOLPHTHALEÏN) OF JUICES, SIRUPS, MASSECUITES, AND SUGAR OF A FACTORY FOR DIFFERENT YEARS.

Method of Boiling.	Sirups blank boiled.						Boiled to grain.			
	1896–97.		1897–98.		1898–99.		1900–01.		1901–02.	
	Pol.	Alk.	Pol.	Alk.	Pol.	Alk.	Pol.	Alk.	Pol.	Alk.
Juice, I saturation.	—	0.082	—	0.072	—	0.087	—	0.084	—	0.089
Juice, II saturation.	—	0.021	—	0.043	—	0.048	—	0.043	—	0.039
Thin juice..........	10.2	0.021	10.7	0.042	10.9	0.047	10.5	0.041	10.1	0.034
Unsat. thick juice ..	—	—	—	0.100	—	0.110	—	0.095	—	0.093
Sat. thick juice.....	53.5	0.034	51.5	0.035	48.0	0.039	50.6	0.030	52.8	0.033
Massecuite cooked with sirup........	82.6	0.038	83.3	0.063	83.5	0.064	83.5	0.044	82.2	0.043
I. Raw sugar.....	95.2	0.006	96.0	0.011	96.1	0.011	96.4	0.011	96.4	0.008
I. Purgings.......	54.2	0.100	57.9	0.109	56.5	0.110	59.0	0.046	58.9	0.104
II. Massecuite.....	63.5	0.077	66.3	0.108	67.1	0.120	68.5	0.092	67.0	0.082
II. Raw sugar.....	92.2	0.006	93.5	0.016	92.1	0.015	93.2	0.013	93.7	0.012
III. Massecuite.....	55.5	0.092	59.4	0.132	58.7	0.140	—	—	—	—
III. Raw sugar.....	92.1	0.007	92.0	0.024	90.8	0.010	—	—	—	—
Molasses...........	48.3	0.080	48.2	0.120	47.8	0.080	49.5	0.075	50.5	0.103

ANALYSES OF BEETS FROM DIFFERENT PROVINCES.

September 22, 1898.

(Herzfeld, Vereinszeitschrift 1898, S. 828.)

Province.	Average weight in grams.		Proportion of beet to leaves.	Composition.				
	One beet.	Of leaves.		Sugar.	Total ash.	Sole ash.	Nitrogen.	Mark.
Silesia.............	416	516	1.24	12.9	0.95	0.83	0.24	4.95
Pommerania.......	340	217	0.64	16.7	0.72	0.45	0.20	4.37
Saxony 1..........	458	363	0.71	16.6	1.01	0.82	0.21	5.15
Saxony 2..........	320	300	0.94	14.9	0.82	0.60	0.16	5.23
Hanover...........	412	321	0.78	15.2	1.03	0.48	0.17	4.84
Rhine.............	352	428	1.22	13.7	1.12	0.59	0.18	4.71

Analysis of Diffusion Juices, Massecuites, and Molasses from Bohemian Factories.

(Andrlik, Böhm. Zeitschrift 1900, S. 203–264; 1901, S. 247; und 1907, S. 441.)

(Campaign 1898–99.)

Factory.	Diffusion juice.					Massecuite.				
	a	*b*	*c*	*d*	*e*	*a*	*b*	*c*	*d*	*e*
Polarization. .	—	—	—	—	—	90.7	90.5	87.6	87.15	85.75
Water........	—	—	—	—	—	3.06	4.72	4.55	4.88	6.02
Ash (carb'n'd)	—	—	—	—	—	2.14	2.16	2.49	2.66	2.32
Org. non-sugar	—	—	—	—	—	4.10	3.62	5.36	5.32	5.91
Quotient......	—	—	—	—	—	93.5	93.9	91.8	91.6	91.2
Org.non-sugar: Ash........	—	—	—	—	—	1.9	1.7	2.1	2.0	2.5
Alk. phenol.	—	—	—	—	—	0.017	0.004	acid	0.028	acid
	On 100 parts of dry substance.									
Total ash.....	2.77	3.09	3.81	3.79	3.23	2.21	2.24	2.61	2.80	2.47
Potash.....	1.34	1.36	1.72	1.55	1.40	1.25	1.19	1.37	1.59	1.41
Soda.......	0.12	0.09	0.16	0.19	0.11	0.15	0.20	0.27	0.19	0.13
Lime.......	0.06	0.04	0.03	0.06	0.12	0.01	0.02	0.02	0.03	0.04
Phos. acid..	0.37	0.49	0.64	0.49	0.35	0.005	0.011	0.003	0.014	0.009
Sulph. acid .	0.22	0.17	0.18	0.24	0.24	0.13	0.17	0.10	0.14	0.17
Chlorine....	0.05	0.08	0.07	0.08	0.09	0.10	0.06	0.07	0.07	0.07
Total nitrogen	0.87	0.90	0.75	1.31	0.80	0.37	0.41	0.56	0.45	0.57
Albuminoid nitrogen..	0.30	0.28	0.26	0.29	0.32	0.03	0.03	0.05	0.04	0.04
Ammonia nitrogen....	0.11	0.15	0.09	0.11	0.10	0.06	0.03	0.05	0.03	0.02
Amino acid nitrogen..	0.44	0.21	0.32	0.38	0.33	0.24	0.26	0.40	0.27	0.44
Oxalic acid ...	0.40	0.80	0.91	0.66	0.66	—	—	—	—	—

COMPARATIVE SUMMARY

OF THE COMPOSITION OF DIFFERENT JUICES OF 1899–1900 (NORMAL WEATHER) AND THOSE OF 1904–5 (VERY DRY YEAR) PER 100 PARTS SUGAR.

Per 100 parts sugar.	1899-1900.	1904-05.
Potash	1.58	1.11
Soda	0.22	0.17
Sulphuric acid	0.19	0.21
Chlorine	0.08	0.06
Phosphoric acid	0.47	0.27
Oxalic acid	0.71	0.49
Total nitrogen	0.72	0.93
Albuminoid nitrogen	0.24	0.22
Ammonia and amino nitrogen	0.10	0.17
Betain nitrogen	0.10	0.24
Other nitrogen	0.28	0.29
Acidity	0.53	0.36

MOLASSES.

Factory.	1	2	3	4	5	6	7	8
Polarization	47.2	48.0	47.4	46.6	49.0	47.4	47.2	51.1
Saccharose (Herzfeld)	48.8	49.8	47.9	47.9	49.2	47.7	47.5	51.5
Water	21.64	20.35	20.66	18.14	16.87	19.91	22.49	18.80
Ash (carbonated)	8.68	9.14	8.71	10.10	10.95	10.49	9.54	9.11
Organic non-sugar	20.88	20.71	22.77	23.86	22.98	21.90	20.43	20.63
Quotient	62.3	62.5	60.3	58.5	59.2	59.6	61.3	63.4
Organic non-sugar: Ash	2.4	2.3	2.6	2.4	2.1	2.1	2.2	2.3
	In 100 parts dry substance.							
Total ash	11.08	11.48	10.98	12.37	13.18	13.10	12.31	11.21
Potash	6.29	6.52	6.26	6.66	7.07	6.60	6.71	6.20
Soda	0.84	0.87	0.81	1.00	1.09	1.41	0.72	1.09
Lime	0.14	0.22	0.19	0.14	0.21	0.19	0.59	0.09
Magnesia	0.04	0.04	0.04	0.21	0.03	0.04	0.05	0.05
Phosphoric acid	0.01	0.03	0.04	0.04	0.08	0.07	0.04	0.10
Sulphuric acid	0.18	0.21	0.17	0.56	0.37	0.31	0.15	0.16
Chlorine	0.38	0.42	0.39	0.48	0.48	0.50	0.43	0.37
Total nitrogen	2.22	2.47	2.37	2.62	2.50	2.40	2.41	2.24
Albuminoid nitrogen	0.22	0.18	0.26	0.19	0.14	0.13	0.29	0.17
Ammonia nitrogen	0.07	0.06	0.04	0.09	0.07	0.08	0.07	0.05
Amino acid nitrogen	1.24	1.36	1.15	1.47	1.59	1.63	1.22	1.46
Nitrate nitrogen	0.06	0.07	0.06	0.02	0.09	0.02	0.04	0.02

APPENDIX I.

FORMULÆ AND TABLES.

THE following tables, formulæ, and general data are those which interest the technical sugar men chiefly. It seems wise to add them to the book, partly because they are not generally given in the other works and calendars on sugar-making, or at best in an incomplete or incomprehensive form. Only those tables and formulæ are given which it is believed may prove of benefit particularly in the factory control.

FORMULÆ.

1. *Formula for calculating the weight of water* (W) *which must be evaporated from G pounds of thin juice at $b°$ Brix to give a thick juice of $B°$ Brix:*

$$W = G\left(1 - \frac{b}{B}\right).$$

2. *Formula for calculating the amount* (F) *of thick juice (massecuite) of $B°$ Brix which will be obtained from G pounds of thin juice at $b°$ Brix:*

$$F = G\frac{b}{B}.$$

Remark: In the above formulæ for accurate computation the true weight of the dry substance should be taken rather than the apparent weight.

3. Formulæ for calculating yield:

Let F_t, Z_t, S_t = the dry substance contained respectively in the massecuite, the sugar, and the sirup;

F_p, Z_p, S_p = polarization of the massecuite, the sugar, and the sirup;

F_q, Z_q, S_q = the quotient (true) of the massecuite, the sugar, and the sirup;

x = yield in per cent.

(*a*) Hulla-Suchomel's formula:

$$x = 100\frac{F_t(F_q - S_q)}{Z_t(Z_q - S_q)}.$$

(*b*) Schneider's formula:

$$x=100\frac{F_p-S_p}{Z_p-S_p}.$$

(*c*) Neumann's formula:

$$x=100\frac{F_t-S_t}{Z_t-S_t}.$$

Remark.—Formula (*a*) is generally applicable, even when the centrifugated sirup has been diluted in any way; formulæ (*b*) and (*c*) can be used only when there has been no dilution of the juice during centrifugation.

4. Saturation formula for sirups:

A sirup saturated at the temperature t, of true purity q, has the following composition (amount of water W, amount of sugar present Z) if the saturation ratio between a pure-sugar solution at the temperature $t=L_t$ and the coefficient of saturation is c:

$$W=\frac{q}{L_t\cdot c+0.01q},$$

$$Z=(100-W)\frac{q}{100}.$$

If the composition of a sirup supersaturated in a definite way is to be obtained, then the coefficient c in the above formula should be multiplied by the corresponding supersaturation-coefficient c_1, and the formula is then

$$W=\frac{q}{L_tc\cdot c_1-0.01q}.$$

5. Formulæ for evaporation and heating:

(*a*) Total heat of the saturated steam is

$$\lambda=606.5+0.305t.$$

(*b*) The heat of evaporation of the saturated steam is

$$r=606.6-0.695t,$$

where t is the temperature of the steam.

(*c*) The amount of steam (S) required for the evaporation of one kilogram (2.2 lbs.) of water, when the temperature of the boiling

juice is t_s, that of the steam is t_d, and that of the condensed water t_c, is

$$S=\frac{606.5-0.695t_s}{606.5+0.305t_d-t_c},$$

or if t_d is made equal to t_c, which is approximately true, then

$$S=\frac{606.5-0.695t_s}{606.5-0.695t_d}.$$

(*d*) Calculation of the amount of steam (S) required for heating one kilogram (2.2 lbs.) of juice in the preheaters when the temperature of the steam is t_d, of the condensed water t_c, of the juice on entering t_1 and on leaving t_2:

$$S=\frac{t_2-t_1}{606.5+0.305(t_d-t_c)}.$$

(*e*) The amount of steam (S) for heating one kilogram of juice by direct steam, using the same notation as under (*d*):

$$S=\frac{t_2-t_1}{606.5+0.305(t_d-t_2)}.$$

6. **Formula for the condensation of steam:**

The amount of water (W) required to condense one kilogram (2.2 lbs.) of steam when its temperature is t_d, that of the injected water is t_i, and of the condenser-water is t^f, is

$$W=\frac{606\cdot5+0\cdot305(t_d-t_f)}{t_f-t_i}.$$

7. **Formula for the heat transmission through a metal wall.**

$$H=AC\frac{t_a-t_b}{D};$$

H is the total quantity of heat, A the area of heating surface, t_a-t_b the temperature fall, D the thickness of the wall in millimeters, and C the conductivity coefficient for the material

composing the wall (C for brass being 1700, for iron 1400, and for water 14).

In calculations based on this formula, the thickness of the heat wall is to be increased to allow for the thickness of moving film of water or liquor, an undetermined value which can only be approximated, being expressed in millimeters of metal of the same conductivity.

8. **Formula for the fire-room.**

(*a*) The excess of air

$$= \frac{CO_2 \sim \text{theoretical air necessary (18.9 for coal)}}{CO_2 \text{ found in flue gases}}.$$

(*b*) The heat lost in the flue gases $= \dfrac{T-t}{CO_2 \text{ found}} k$, where $k = 0.66$,

T = temperature of flue gases, and t = the temperature of the air.

TABLES.

1. Solubility of Lime in Water.

(Herzfeld, Deutsche Vereinszeitschrift, 1897, p. 819.)

At the temperature of	Parts of water for one part CaO.	At the temperature of	Parts of water for one part CaO.
15° C.	776	50° C.	1044
20° C.	813	55° C.	1108
25° C.	848	60° C.	1158
30° C.	885	65° C.	1244
35° C.	924	70° C.	1330
40° C.	962	75° C.	1410
45° C.	1004	80° C.	1482

2. Solubility of Lime in Sugar Solutions.

According to Lamy, there will dissolve in 100 grams of ten per cent sugar solution

At 0°	....	25.0 grams CaO
" 15°	....	21.5 " "
" 30°	....	12.0 " "
" 50°	....	5.3 " "
" 70°	....	2.3 " "
" 100°	....	1.55 " "

Remark.—The solubility of lime in sugar solution depends not alone upon the temperature and the amount of sugar in solution, but also upon the nature of the lime added, as well as the duration of the action.

3. Table showing the Amount of Caustic Lime contained in Milk of Lime at 15° C. (Blattner).

Deg. Brix.	Degree Baumé.	Weight of one litre milk of lime.	CaO per litre.	Per cent CaO.	Deg. Brix.	Degree Baumé.	Weight of one litre milk of lime.	CaO per litre.	Per cent CaO.
		grams.	grams.				grams.	grams.	
1.8	1	1007	7.5	0.745	29	16	1125	159	14.13
3.6	2	1014	16.5	1.64	30.8	17	1134	170	15
5.4	3	1022	26	2.54	32.7	18	1142	181	15.85
7.2	4	1029	36	3.5	34.6	19	1152	193	16.75
9	5	1037	46	4.43	36.4	20	1162	206	17.72
10.8	6	1045	56	5.36	38.3	21	1171	218	18.61
12.6	7	1052	65	6.18	40.1	22	1180	229	19.4
14.4	8	1060	75	7.08	42	23	1190	242	20.34
16.2	9	1067	84	7.87	43.9	24	1200	255	21.25
18	10	1075	94	8.74	45.8	25	1210	268	22.15
19.8	11	1083	104	9.6	47.7	26	1220	281	23.03
21.7	12	1091	115	10.54	49.6	27	1231	295	23.96
23.5	13	1100	126	11.45	51.5	28	1241	309	24.9
25.3	14	1108	137	12.35	53.5	29	1252	324	25.87
27.2	15	1116	148	13.26	55.4	30	1263	339	26.84

4. Table showing the Solubility of Sugar in Water at Different Temperatures.

(Recalculated from Herzfeld, Deutsche Vereinszeitschrift, 1892, p. 181.)

One part of water will dissolve—

Temperature. C.°	Parts of sugar.	Temperature, C.°	Parts of sugar.	Temperature, C.°	Parts of sugar.	Temperature, C.°	Parts of sugar.
0	1.79						
1	1.80	26	2.12	51	2.62	76	3.44
2	1.81	27	2.14	52	2.65	77	3.48
3	1.82	28	2.16	53	2.67	78	3.52
4	1.83	29	2.17	54	2.70	79	3.57
5	1.84	30	2.19	55	2.73	80	3.62
6	1.86	31	2.21	56	2.75	81	3.66
7	1.87	32	2.23	57	2.78	82	3.71
8	1.88	33	2.25	58	2.81	83	3.76
9	1.89	34	2.27	59	2.84	84	3.81
10	1.90	35	2.29	60	2.87	85	3.86
11	1.91	36	2.30	61	2.90	86	3.92
12	1.92	37	2.32	62	2.93	87	3.98
13	1.94	38	2.34	63	2.96	88	4.03
14	1.96	39	2.36	64	2.99	89	4.09
15	1.97	40	2.38	65	3.03	90	4.15
16	1.98	41	2.40	66	3.06	91	4.21
17	1.99	42	2.42	67	3.09	92	4.28
18	2.01	43	2.44	68	3.13	93	4.35
19	2.02	44	2.46	69	3.16	94	4.42
20	2.04	45	2.48	70	3.20	95	4.48
21	2.05	46	2.51	71	3.24	96	4.55
22	2.07	47	2.53	72	3.28	97	4.63
23	2.08	48	2.55	73	3.31	98	4.71
24	2.09	49	2.58	74	3.35	99	4.79
25	2.11	50	2.60	75	3.40	100	4.87

5. Table of Temperatures corresponding to the Tensions of Saturated Steam.

(Claassen, Deutsche Vereinszeitschrift, 1893. p. 268.)

I. For Evaporation.

(*a*) From 0 to 75 cm. vacuum.

Absolute pressure in cm.	Vacuum.		Temperature.		Absolute pressure in cm.	Vacuum.		Temperature.	
	cm.	inches.	C.°	F.°		cm.	inches.	C.°	F.°
1	75	29.5	11.3	52.3	23.5	52.5	20.7	70.2	158
2	74	29.1	22.4	72.3	24	52	20.5	70.7	159
3	73	28.7	29.1	84.4	24.5	51.5	20.3	71.2	160
4	72	28.3	34.2	93.6	25	51	20.1	71.6	161
5	71	27.9	38.3	101	25.5	50.5	19.9	72.1	162
6	70	27.6	41.7	107	26	50	19.7	72.5	162
6.5	69.5	27.4	43.2	110	26.5	49.5	19.5	73.0	163
7	69	27.2	44.6	112	27	49	19.3	73.4	164
7.5	68.5	27.0	46.0	115	27.5	48.5	19.1	73.9	165
8	68	26.8	47.2	117	28	48	18.9	74.3	166
8.5	67.5	26.6	48.4	119	28.5	47.5	18.7	74.7	166
9	67	26.4	49.6	121	29	47	18.5	75.1	167
9.5	66.5	26.2	50.7	123	29.5	46.5	18.3	75.5	168
10	66	26.0	51.7	125	30	46	18.1	75.9	169
10.5	65.5	25.8	52.7	127	30.5	45.5	17.9	76.3	169
11	65	25.6	53.6	128	31	45	17.7	76.7	170
11.5	64.5	25.4	54.5	130	31.5	44.5	17.5	77.1	171
12	64	25.2	55.4	132	32	44	17.3	77.5	171
12.5	63.5	25.0	56.3	133	32.5	43.5	17.1	77.9	172
13	63	24.8	57.2	135	33	43	16.9	78.2	173
13.5	62.5	24.6	58.0	136	33.5	42.5	16.7	78.6	173
14	62	24.4	58.7	138	34.	42	16.5	79.0	174
14.5	61.5	24.2	59.5	139	34.5	41.5	16.3	79.3	175
15	61	24.0	60.2	140	35	41	16.1	79.7	175
15.5	60.5	23.8	61.0	142	35.5	40.5	15.9	80.0	176
16	60	23.6	61.6	143	36	40	15.7	80.4	177
16.5	59.5	23.4	62.3	144	37	39	15.3	81.0	178
17	59	23.2	63.0	145	38	38	15.0	81.7	179
17.5	58.5	23.0	63.6	146	39	37	14.6	82.4	180
18	58	22.8	64.2	148	40	36	14.2	83.0	181
18.5	57.5	22.6	64.8	149	41	35	13.8	83.6	182
19	57	22.4	65.4	150	42	34	13.4	84.2	184
19.5	56.5	22.2	66.0	151	43	33	13.0	84.8	185
20	56	22.0	66.5	152	44	32	12.6	85.4	186
20.5	55.5	21.8	67.1	153	45	31	12.2	86.0	187
21	55	21.6	67.6	154	46	30	11.8	86.5	188
21.5	54.5	21.5	68.1	155	47	29	11.4	87.1	189
22	54	21.3	68.7	156	48	28	11.0	87.7	190
22.5	53.5	21.1	69.2	157	49	27	10.6	88.2	191
23	53	20.9	69.7	157	50	26	10.2	88.7	192

5a. TABLE OF TEMPERATURES CORRESPONDING TO THE TENSIONS OF SATURATED STEAM.—*Continued.*

Absolute pressure in cm.	Vacuum.		Temperature.		Absolute pressure in cm.	Vacuum.		Temperature.	
	cm.	inches.	C.°	F.°		cm.	inches.	C.°	F.°
51	25	9.84	89.2	193	64	12	4.72	95.3	203
52	24	9.45	89.7	193	65	11	4.33	95.7	204
53	23	9.06	90.2	194	66	10	3.94	96.1	205
54	22	8.66	90.7	195	67	9	3.54	96.5	206
55	21	8.27	91.2	196	68	8	3.15	96.9	206
56	20	7.87	91.7	197	69	7	2.76	97.3	207
57	19	7.48	92.2	198	70	6	2.36	97.7	208
58	18	7.09	92.6	199	71	5	1.97	98.1	209
59	17	6.70	93.1	200	72	4	1.57	98.5	209
60	16	6.30	93.5	200	73	3	1.18	98.9	210
61	15	5.91	94.0	201	74	2	.79	99.3	211
62	14	5.51	94.4	202	75	1	.39	99.6	211
63	13	5.12	94.8	203	76	0	.0	100.0	212

5.—(*b*) FROM 0 TO 1 ATMOSPHERE EXCESS PRESSURE.

Absolute pressure in cm. of mercury.	Pressure over one atmosphere		Temperature.		Absolute pressure in cm. of mercury.	Pressure over one atmosphere		Temperature.	
	in cm. of mercury.	in lbs. per sq. in.	C°	F°		in cm. of mercury.	in lbs. per sq. in.	C°	F°
76	0	0	100.0	212.0	115	39	7.53	112.0	233.5
77	1	0.19	100.4	212.7	116	40	7.72	112.2	234.0
78	2	0.39	100.7	213.3	117	41	7.91	112.4	234.5
79	3	0.58	101.1	214.0	118	42	8.11	112.7	235.0
80	4	0.77	101.4	214.6	119	43	8.30	112.9	235.5
81	5	0.96	101.8	215.2	120	44	8.49	113.2	235.9
82	6	1.15	102.1	215.8	121	45	8.68	113.5	236.3
83	7	1.35	102.5	216.4	122	46	8.87	113.7	236.7
84	8	1.54	102.8	217.0	123	47	9.07	113.9	237.1
85	9	1.74	103.2	217.6	124	48	9.26	114.2	237.6
86	10	1.93	103.5	218.2	125	49	9.46	114.4	238.0
87	11	2.12	103.8	218.8	126	50	9.65	114.7	238.4
88	12	2.32	104.1	219.4	127	51	9.84	114.9	238.8
89	13	2.51	104.4	220.0	128	52	10.04	115.2	239.3
90	14	2.70	104.7	220.6	129	53	10.23	115.4	239.8
91	15	2.89	105.1	221.2	130	54	10.42	115.7	240.2
92	16	3.08	105.4	221.7	131	55	10.61	115.9	240.6
93	17	3.28	105.7	222.3	132	56	10.80	116.1	241.0
94	18	3.47	106.0	222.8	133	57	11.00	116.3	241.4
95	19	3.67	106.3	223.3	134	58	11.19	116.6	241.8
96	20	3.86	106.6	223.9	135	59	11.39	116.8	242.2
97	21	4.05	106.9	224.4	136	60	11.58	117.1	242.7
98	22	4.25	107.2	225.0	137	61	11.77	117.3	243.1
99	23	4.44	107.5	225.5	138	62	11.97	117.5	243.5
100	24	4.63	107.8	226.0	139	63	12.16	117.8	244.0
101	25	4.82	108.1	226.6	140	64	12.35	118.0	244.4
102	26	5.01	108.4	227.1	141	65	12.54	118.3	244.9
103	27	5.21	108.7	227.7	142	66	12.73	118.5	245.3
104	28	5.40	109.0	228.2	143	67	12.93	118.7	245.7
105	29	5.59	109.3	228.7	144	68	13.12	118.9	246.1
106	30	5.79	109.6	229.2	145	69	13.32	119.1	246.5
107	31	5.98	109.8	229.7	146	70	13.51	119.4	246.9
108	32	6.18	110.1	230.2	147	71	13.70	119.6	247.3
109	33	6.37	110.3	230.6	148	72	13.90	119.8	247.7
110	34	6.56	110.6	231.1	149	73	14.09	120.0	248.0
111	35	6.75	110.9	231.6	150	74	14.28	120.2	248.4
112	36	6.94	111.1	232.0	151	75	14.47	120.4	248.7
113	37	7.14	111.4	232.5	152	76	14.67	120.6	249.1
114	38	7.33	111.7	233.0					

5.—(*c*) Relation between the different units for measuring vacuo

Atmospheres at absolute pressure.	Atmospheres of vacuo	Kilos of absolute pressure.	Kilos at vacuo.	Millimetres of mercury, absolute pressure.	Millimetres of mercury, vacuo.	Inches of mercury, absolute pressure.	Inches of mercury, vacuo.
0.1	0.9	0.103	0.930	76	684	3	27
0.2	0.8	0.207	0.826	152	608	6	24
0.3	0.7	0.310	0.723	228	532	9	21
0.4	0.6	0.413	0.620	304	456	12	18
0.5	0.5	0.517	0.516	380	380	15	15
0.6	0.4	0.620	0.413	456	304	18	12
0.7	0.3	0.723	0.310	532	228	21	9
0.8	0.2	0.827	0.206	608	152	24	6
0.9	0.1	0.930	0.103	684	76	27	3
1.0	0.0	1.033	0.000	760	000	30	0

(*d*) Relation between the Different Units for Measuring Pressure.

Atmospheres of absolute pressure.	Atmospheres of pressure.	Kilos per sq. cm.	Pounds per sq. in.	Atmospheres of absolute pressure.	Atmospheres of pressure.	Kilos per sq. cm.	Pounds per sq. in.
1	0	0	0	7	6	6.200	88.0
2	1	1.033	14.7	8	7	7.234	102.7
3	2	2.067	29.3	9	8	8.267	117.4
4	3	3.100	44.0	10	9	9.301	132.1
5	4	4.134	58.7	11	10	10.334	146.7
6	5	5.167	73.4				

5.—II. Table for the Boiler House (Fliegener's).

0.1 to 10 Atmospheres.

Pressure.			Temperature.	
Kilos per sq. cm.	Centimeters of mercury.	Pounds per sq. inch.	Centigrade.	Fahrenheit.
0.1	7.355	1.42	45.6	114.1
0.2	14.71	2.84	59.8	139.6
0.3	22.07	4.26	68.7	155.7
0.4	29.42	5.68	75.5	167.9
0.5	36.78	7.11	80.9	177.6
0.6	44.13	8.51	85.5	185.9
0.7	51.49	9.95	89.5	193.1
0.8	58.84	11.36	93.0	199.4
0.9	66.20	12.79	96.2	205.2
1.0	73.55	14.21	99.1	210.4
1.5	110.3	21.32	110.8	231.4
2.0	147.1	28.42	119.6	247.3
2.5	183.9	35.53	126.7	260.1
3.0	220.7	42.63	132.8	271.0
3.5	257.4	49.74	138.1	280.6
4.0	294.2	56.84	142.8	289.0
4.5	331.0	63.95	147.1	296.8
5.0	367.8	71.05	151.0	303.8
5.5	404.5	78.16	154.6	310.3
6.0	441.3	85.26	157.9	316.2
6.5	478.1	92.27	161.1	322.0
7.0	514.9	99.47	164.0	327.2
7.5	551.6	106.58	166.8	332.2
8.0	488.4	113.7	169.5	337.1
8.5	625.2	120.8	172.0	341.6
9.0	662.0	127.9	174.4	345.9
9.5	698.7	135.0	176.7	350.1
10.0	735.5	142.1	178.9	354.0

6. Table Showing the Specific Heat of Steam at Different Pressures and Temperatures.
(Zeitschrift Deutscher Ing. 1907, Nr. 3 u. 4.)
Values of C_p.

Pressure, Atm. kg. per 1 cm²	1	2	4	6	8	10	12	20
Saturation temperature. C°.	99	120	143	158	169	179	187	211
	Specific Heats.							
At the saturation temp'ture	0.463	0.480	0.513	0.548	0.583	0.621	0.660	0.865
At 100	0.463	—	—	—	—	—	—	—
At 150	0.462	0.476	0.510	—	—	—	—	—
At 200	0.462	0.472	0.492	0.513	0.538	0.572	0.613	—
At 250	0.466	0.473	0.484	0.491	0.499	0.506	0.514	0.559
At 300	0.474	0.478	0.485	0.490	0.493	0.497	0.500	0.508
At 350	0.490	0.492	0.497	0.500	0.503	0.506	0.508	0.513
At 400	0.511	0.512	0.515	0.517	0.519	0.521	0.522	0.527

7. Table Showing the Increase in Boiling-point of Pure and Impure Sugar Solutions.
Claassen (Vereinszeitschrift 1904, S. 1161.)

Per cent of Dry substances in solution.	Increase in boiling point for a solution of purity.									
	100		93		83		73		62	
	C°	F°	C°	F°	C°	F°	C°	F°	C°	F°
5	0.05	0.09	0.05	0.09	0.05	0.09	0.05	0.09	0.05	0.09
10	0.1	0.18	0.1	0.18	0.1	0.18	0.15	0.27	0.2	0.36
15	0.2	0.36	0.2	0.36	0.25	0.45	0.25	0.45	0.35	0.63
20	0.3	0.54	0.3	0.54	0.35	0.63	0.40	0.72	0.5	0.90
25	0.45	0.81	0.45	0.81	0.5	0.9	0.6	1.1	0.75	1.4
30	0.6	1.1	0.65	1.2	0.7	1.3	0.85	1.6	1.1	2.0
35	0.8	1.4	0.85	1.5	1.0	1.8	1.2	2.2	1.5	2.7
40	1.05	1.9	1.15	2.0	1.35	2.4	1.6	2.9	1.95	3.5
45	1.4	2.5	1.55	2.8	1.75	3.2	2.1	3.8	2.5	4.5
50	1.8	3.2	2.0	3.6	2.25	4.0	2.7	4.9	3.15	5.7
55	2.3	4.1	2.6	4.7	3.0	5.4	3.5	6.3	4.0	7.2
60	3.0	5.4	3.3	5.9	3.8	6.9	4.5	8.1	5.0	9.0
65	3.8	6.9	4.25	7.7	4.8	8.7	5.6	10.1	6.2	11.2
70	5.1	9.2	5.4	9.7	6.2	12.1	7.0	12.6	8.0	15.4
75	7.0	12.6	7.3	13.1	8.5	16.3	9.2	16.6	10.3	18.5
80	9.4	16.9	10.0	18.0	11.4	20.5	12.2	22.0	13.6	24.5
85	13.0	23.4	13.4	24.1	15.9	28.6	16.9	30.4	18.2	32.8
90	19.6	33.3	(20.0)	(36.0)	(22.0)	(39.6)	24.7	44.5	26.9	48.4
92	24.0	43.2	—	—	—	—	—	—	—	—
94	30.5	54.9	—	—	—	—	—	—	—	—

8. Table giving the Specific Heats of Sugar Solutions.

(Cf. Curin, Oest. Zeitschrift, 1894, p. 988.)

Degree Brix.	Specific heat according to		Degree Brix.	Specific heat according to	
	Kopp.	Marignac.		Kopp.	Marignac.
1	0.993	0.994	60	0.605	0.652
10	0.934	0.942	70	0.539	0.594
20	0.868	0.884	80	0.474	0.536
30	0.803	0.826	90	0.408	0.478
40	0.737	0.768	99	0.349	0.426
50	0.671	0.710			

9. Table showing Sugar-losses in the Evaporation of Alkaline Juices.

(Cf. Herzfeld, Deutsche Vereinszeitschrift, 1893, p. 754.)

Sugar-losses for 100 parts of sugar in one hour.

Boiling temperature in 0° C.	Sugar-content of the juice.				
	10%	20%	30%	40%	50%
80	0.0444	0.0301	0.0157	0.0179	0.0200
85	0.0615	0.0421	0.0223	0.0262	0.0296
90	0.0790	0.0541	0.0290	0.0344	0.0392
95	0.0965	0.0661	0.0357	0.0427	0.0488
100	0.1140	0.0781	0.0423	0.0508	0.0584
105	0.1385	0.0937	0.0490	0.0588	0.0680
110	0.1630	0.1093	0.0557	0.0667	0.0776
115	0.1749	0.1187	0.0623	0.0748	0.0862
120	0.2823	0.2341	0.1857	0.2269	0.2678
125	0.5330	0.5082	0.4833	0.5939	0.7044
130	2.0553	1.4610	0.8667	1.0235	1.1800
135	3.5776	—	—	—	—
140	5.1000	—	—	—	—

10. Tables showing Influence of Purity on Yield.

(Claassen, D. Zuckerind. 1894, p. 956.)

I. On Yield of Raw-sugar.

(a) Influence of purity of massecuite when purity of centrifugalled sirup is 72.				(b) Influence of purity of centrifugalled sirup when purity of massecuite is 91.		
Massecuite. Total solids.	Massecuite. Purity.	Yield of raw sugar (92°) as per cent of massecuite.	Increase of yield per 1 per cent increase in purity.	Purity of sirup.	Yield of raw sugar (92°) as per cent of massecuite.	Increase of yield per 1 per cent increase in purity.
94	88	59.0	—	75	66.7	—
94	89	62.7	3.7	74	67.9	1.2
94	90	66.4	3.7	73	69.1	1.2
94	91	70.1	3.7	72	70.1	1.0
94	92	73.8	3.7	71	71.0	0.9
94	93	77.5	3.7	70	71.9	0.9
94	94	81.2	3.7	69	72.7	0.8
94	95	84.9	3.7	68	73.5	0.8
—	—	—	—	67	74.2	0.7
—	—	—	—	66	74.9	0.7

II. On Yield of Molasses.

Percentage Yield on Weight of Beets of Molasses containing 20% Water.

From 16% a Yield of First Massecuite and a True Purity of the Molasses of 62.

True purity of the massecuite or thick juice.	Average polarization of the sugar. 94	95	96	97	100
	Molasses in per cent of the beets.				
90	3.3	3.6	4.0	4.3	4.9
91	2.7	3.1	3.4	3.8	4.4
92	2.1	2.6	2.9	3.3	4.0
93	1.6	2.0	2.4	2.8	3.5
94	1.1	1.5	1.9	2.4	3.0
95	0.6	0.9	1.4	1.9	2.5
96	0.0	0.4	0.8	1.5	2.0

Various Data.

One cubic meter weighs:

Washed beets	550 to 600	kilos
Fresh residuum, cosettes	600	"
Soured residuum, cosettes	800	"
Furnace coke	420	"
Gas coke	350	"
Limestone	1600	"
Lime	775 to 950	"
Slaked-lime paste	1200	"
Raw sugar, *firsts*, loosely piled up	875	"
" " *seconds*, loosely piled up	780	"
Hot massecuite	1450 to 1470	"

Specific Weights.

Sugar	1.61
Limestone	2.36 to 2.74
Lime	2.3 to 4.2

Weight of Gases at 0° and 760 mm. Atmospheric Pressure.

1 litre of air	1.293	grams
1 " of oxygen	1.430	"
1 " of nitrogen	1.256	"
1 " of carbonic acid	1.977	"
1 " of sulphurous acid	2.909	"
1 " carbon monoxide	1.250	"
1 " steam at 100° C.	0.506	"
1 " hydrogen	0.089	"
1 " illuminating-gas	0.517	"

Specific Heat of Gases at Constant Pressure.

Air	0.2375
Oxygen	0.2175
Nitrogen	0.2438
Carbon dioxide	0.2396
Carbon monoxide	0.2450
Hydrogen	3.4090
Steam (old value)	0.4750

(For new value see Table VI.)

Coefficient of Heat Transmission, Data Obtained in Practice (according to Jelinek).

Triple effect:
- 1st compartment 37 calories
- 2d " 25 "
- 3d " 14 "

Quadruple effect:
- 1st compartment 28 calories
- 2d " 26 "
- 3d " 20 "
- 4th " 5 to 6 calories

Vacuum-pan for after-products 6 to 7 calories.

" " massecuite, 1st:
- Until grain formation, 18 calories
- During graining, 10 calories
- During thickening, 3.7 calories

According to Claassen:

Triple effect:
- 1st compartment, fall of 5°.5 temperature, juice at 10° Brix, 40 to 50 calories
- 2d " " " 7°.5 " juice at 20° to 25° Brix, 30 to 35 calories
- 3d " " " 24° temperature, juice at 55° to 62° Brix, 15 to 20 calories

Experiments Conducted on a Small Scale at the Atmospheric Pressure (according to Sulzer).

Kind of tube.	Thickness, mm.	Coefficient of heat transmission for the steam used at the temperature of 110 °C.	117 °C.	125 °C.	131.3 °C.	136.5 °C.	141.6 °C.
1. Drawn-copper tube	2.5	—	47.3	57.2	63.3	62.3	54.2
2. Wt.-iron tube, riveted and enameled	2.1	—	33.3	35.3	35.8	37.7	35.3
3. Wt.-iron tube, riveted but not enam.	2.1	—	38.0	36.7	39.2	39.2	37.8
4. Welded wrought-iron boiler tube	4.5	—	40.5	42.8	44.8	45.5	43.3
5. Rough cast-iron tube	10	—	25.8	32.2	31.5	31.3	32.3
6. Welded wrought-iron tube	13	—	23.2	24.7	26.2	25.5	24.7
7. Riveted steel enameled tube	1.85	19.0	26.2	31.3	33.0	38.3	—
8. Cast-iron smoothly turned tube	15.25	17.7	20.5	24.5	25.0	26.0	25.7
9. Cast-iron corrugated tube	13.5	26.2	24.8	28.0	28.7	30.0	29.7

In the preheater for diffusion juices with moderate circulation, 2 to 3 calories.
" " " " " " " rapid circulation, 6 to 10 calories.

Decomposition of Sugar in Alkaline Solutions.

1 cu. cm. of a caustic potash 1/10 normal (containing 0.0047 grams K_2O = 0.0028 gram CaO) is neutralized by 0.012 gram of inverted sugar or 0.0114 gram of saccharose.

APPENDIX II.*

CALCULATIONS FOR AN EVAPORATING PLANT AND FOR THE STEAM CONSUMPTION IN WORKING UP 100 LBS. OF BEETS.

THE following calculations do not claim to be precise, but only show in a simple way how practical data can be obtained:

Given: The evaporating plant consists of a quadruple effect and juice-cooker. Steam for heating and boiling is taken as follows:

For Diffusion: from First effect.
" First juice-heater: " Fourth effect.
" Second juice-heater: " Second effect.
" Carbonatation juice, thin juice and thickened juice: from First effect.
" Pans: half is taken from the first effect and half from the juice-cooker.

From 100 lbs. of beets are obtained 115 lbs. of diffusion juice and 125 lbs. of carbonatation and thin juices. The thin juice is concentrated from 12° to 60° Brix. The amount of thickened juice will be 25 lbs., and the amount of massecuites 15 lbs. Hence, from the thin juice 100 lbs. of water will have to be evaporated; from the thick juice, 10 lbs.

The specific heat of the beets and thin juices is 0.9, and of the thick juice, 0.6.

* The data in the two appendices following have been expressed in the U. S. units of measurement. As Dr. Claassen has given most of the data in parts per 100, comparatively few of the figures are changed, except those expressing temperature, heat-units, transference coefficients, and heating-surfaces. As in the original calculation, round numbers are given. —TRANSLATORS.

A. For the heating and boiling calculations, the following amounts of steam are used:

1. For the Diffusion: The amount of heat necessary for juice heating is the difference between that in the raw juice, including that in the spent chips and waste waters, and the amount introduced in the beets and water, including cooling losses.

There are 90 lbs. of spent chips and 110 lbs. of waste water. The temperature of the beets is taken at 50° F., that of the pressure-water being 50° F., and of the raw juice 95° F., and of the spent chips and waste waters 68° F.

There is added: (*a*) $100 \times 0.9 \times 18 + 215 \times 18$ B.T.U., and carried away (*b*) $(110+90)36 + 115 \times 0.9 \times 63$ B.T.U.

Heat consumption $(b-a)$: 8230 B.T.U. $= \frac{8230}{970}$ lbs. of steam,

$D = 8.5$ lbs.

2. For heating the raw juice: In the first preheater, from 95° to 122° F.

$115 \times 27 \times 0.9$ B.T.U. or $\frac{2795}{970}$ lbs. of steam, $RJ_1 = 2.9$ lbs.

In the second preheater, from 122° to 185° F.:

$115 \times 63 \times 0.9$ B.T.U. $\frac{6520}{970}$ lbs. steam, $RJ_2 = 6.7$ lbs.

3. For heating during carbonatation:

Cooling during carbonatation and filtration....	13°
" " second carbonatation	18°
Heating from 185° to 212° F.	27°
	58°

$125 \times 58 \times 0.9$ B.T.U. or $\frac{6525}{970}$ lbs. steam, $C = 6.7$ lbs.

4. For reheating the thin juice and boiling, corresponding to 36° F.:

$125 \times 36 \times 0.9$ B.T.U. or $\frac{4050}{970}$ lbs. steam, $TJ = 4.1$ lbs.

5. For heating the concentrated juice from 158° to 212° F.:

$$25 \times 54 \times 0.6 \text{ B.T.U.} \quad \text{or} \quad \frac{810}{970} \text{ lbs. steam,} \qquad TJ = 0.8 \text{ lbs.}$$

6. For boiling the concentrated juice in the pans: By which 10 lbs. of water is evaporated:

$$\frac{10}{0.95} \text{ lbs. of steam} = 10.5 \text{ lbs.}$$

For heating:	1.0	
	11.5 lbs.	$B = 11.5$ lbs.
	Total:	41.2 lbs.

B. Special Consumption of Steam.

1. For heating thin juice from 212° F. to the boiling temperature of the heater, this being done either in the heater or in a special preheater and according to the temperature required taking 2–3 lbs.		2 lbs.
2. For the motive power of engines: For every 100 lbs. of beets worked up there is necessary 0.5–0.7 horse-power hours, one horse-power hour taking heat corresponding to 2.6 lbs. of steam. Heat used in round numbers,		2 lbs.
3. Cooling losses:		
(*a*) In steam lines	3 lbs.	
(*b*) In apparatus, etc.	3 lbs.	
	6 lbs.	6 lbs.
4. Losses from leaks, evaporation, etc.,	(2–3 lbs.)	3 lbs.
Total special steam-consumption,		13 lbs.

The amount of engine exhaust in most factories with ordinary type of engines is usually taken as averaging 30 lbs., those with modern and centralized power averaging 20 lbs. per 100 lbs. of beets.

The following diagram shows the way the steam is taken from the evaporator above described:

Juice-cooker,	Exhaust Steam, =30 I.	II.	III.	IV.
$B=5.5$	$D=$ 8.5	$RJ_2=6.7$		$RJ=2.9$
	$C=$ 6.7			
	$tj=$ 4.1			
	$TJ=$ 0.8			
	$B=$ 6.0			
Total:	$=26.1$			

Designating the amount of steam which the quadruple will evaporate from 100 lbs. of beets as x, this will be found in round numbers:

$$
\begin{array}{ll}
\text{In IV,} & x \\
\text{III,} & x \\
\text{II,} & x+\ 6.7 \\
\text{I,} & x+\ 6.7+26.1 \\
JC, & x+\ 6.7\ \ 26.1+5.1-30 \\
\hline
\text{Total,} & 5x+20.1+52.2+5.5-30=100
\end{array}
$$

Since there are 100 lbs. of water in all to be evaporated:

$$x=10.4 \text{ lbs.}$$

Live steam only passes into the juice-cooker, hence it is here that all the live steam for evaporating as well as for other purposes enters the system.

The whole of the steam necessary for evaporating is:

Live	18.7 lbs.
Exhaust..................	30.0 "
	48.7
Steam specially used (B) . . .	13.0
Total steam used in the factory for 100 lbs. beets	61.7 lbs.

If in the boilers 1 lb. of coal evaporates 8 lbs. of water, the coal consumption will be 7.7 lbs. of water per 100 lbs. of beets. These coal and steam figures apply only when the work is continuous. Interruptions and Sunday rest periods raise them notably.

In the single effects of the evaporating plant as described above, the heat-units transferred or amounts of water evaporated per 100 lbs. of beets are as follows:

	Evaporated.	Heat Transferred.
In juice-cooker	18.7 lbs. water	17,800 B.T.U.
First effect	43.2 "	41,200 "
Second effect	17.1 "	16,600 "
Third effect	10.5 "	10,400 "
Fourth effect	10.5 "	10,600 "
	100.0 lbs. water	

From the vapors passing out of the last effect, 2.9 lbs. will be condensed in the first juice heater, only 7.0 lbs. going to the condenser. From the pans, 11 lbs. of vapors pass off, so that altogether 18 lbs. of waste vapors are condensed per 100 lbs. of beets.

The **amount of condensed water** from the evaporators is distributed as follows:

(*a*) Water at a temperature above 212° F.:

From the exhaust-steam pipe	5 lbs.	
" juice-heater	18.7 "	
" first effect	43.2 "	
" second effect	17.1 "	
		84 lbs.

(*b*) Water at about 212° F.:

From the pans	11.5 lbs.	
" third effect	10.5 "	
" thin-juice heater	4.1 "	
" thick-juice heater	0.8 "	
		26.9 lbs.

(*c*) Water below 212° F.:

From the fourth effect	10.5 lbs.
" diffusion heaters	8.5 "
" diffusion juice-heaters	9.6 "
" carbonatation juice heaters . .	6.7 "
	35.3 lbs.
	146.2 lbs.

Calculation of heating-surface is on the following principle: Since the heat-transference coefficient is the heat transferred from one square foot of surface per degree Fahrenheit of temperature, in order to determine the size of the heating-surface for each vessel it is necessary to divide the heat-units which are transferred in one minute in each vessel, as given above, by the product of the temperature fall and the heat-transference coefficient. For the temperature fall in the preheaters, take the difference between the temperature of the steam used for heating and the mean temperature of the juice entering and leaving the apparatus. In the case of evaporating and boiling apparatus, the difference of temperature between the steam and the boiling liquors should be taken.

CALCULATION OF HEATING-SURFACE FOR 100 LBS. OF BEETS IN 1 MINUTE, CORRESPONDING TO A DAILY WORK OF ABOUT 50 TONS.

Apparatus.	Heat-units, B.T.U.	Temperature Fall in F°.	Heat-trans. Coef. B.T.U.	Heat-surface, Sq. Ft.
Juice-cooker	17,800	18	8.3	120
First effect	41,200	14	7.5	390
Second effect	16,600	16	5.0	210
Third effect	10,400	18	3.3	175
Fourth effect	10,600	31	2.0	170
Raw juice: First preheater	2,800	45	0.8	80
Second preheater . . .	6,500	63	0.8	130
Carbonatation: Juice heater	6,480	36	0.8	225
Thin-juice heater.	4,050	18	1.7	130
Thick-juice heater.	810	54	0.8	20
Vacuum-pans: Firsts	9,720	54	1.7	105
Sirup	970	54	0.8	20

Since the vacuum pans for firsts and for sirup products are not working continuously, and since the juices do not all boil down equally well, it is advisable to provide an excess of from 50 to 100 per cent. over the calculated amount of heating surface required. Still more heating surface is required if the evaporating apparatus is not thoroughly cleaned once a weak, or if there is much scale deposited from the juice. It is not necessary to provide fqr a temporary working-up of more beets, for instead of 50 tons per day, as was assumed, 100 lbs. per minute is actually equivalent to 62 tons per day. This computation, however, is for apparatus for good juice circulation, and does not hold for apparatus of antiquated design.

The heating surfaces in the boilers that is necessary for delivering 62 lbs. of steam per minute (cf. page 329) can be computed according to the following principles: To utilize the coal efficiently, 1 square foot of heating surface should not give, in return flue boilers, more than 4 to 5 lbs. of steam per hour, or 0.07 to 0.08 lb. per minute; in multitubular boilers 2.4 to 3.2 lbs. per hour or 0.04 to 0.05 lb. per minute. Hence for the production of 62 lbs. of steam per minute required for 62 tons of beets daily (here it is not necessary to make a deduction) there are needed in

Return flue boilers............	780 to 925 sq. ft.
Multitubular boilers............	1215 to 1460 "

or for a daily working of 50 U. S. tons,

Return flue boilers............	542 to 710 sq. ft.
Multitubular boilers............	845 to 1015 "

Heat Balance in the Factory,

Calculated for 100 pounds beets worked up.

(*a*) Heat loss in the boiler-house:

Coal consumed, 7.7 lbs, 12,240 B.T.U.	94,250 B.T.U.		
Utilized: 61.7 lbs. of steam which, when the feed water is at 203° F., represents 1000 B.T.U. per lb.	61,700	"	= 66%
Lost	32,550	"	= 34%
			100%

(*b*) Heat losses in the sugar-house:

(The per cents. are on the heat-units utilized in the steam consumed, taken as 61,700 B.T.U.)

1. From the boiler-house to the place where utilized	5,040 B.T.U.		= 8.1%
2. In the condenser waters. In condensation, the calculated amount of steam used is 18.6 lbs. which is increased by various irregularities and by losses in removing ammonia gases, etc., to about 20 lbs. =20×1134 B.T.U.	22,680	"	=36.5%
3. In the dumpings from the diffusion, 200 lbs. =200×18 B.T.U.	3,600	"	= 5.8%
4. In the press-scums, 10 lbs. =10×108 B.T.U.	1,080	"	= 1.7%
5. In the water condensed from the evaporator vapors and not utilized for boiler feed and sweetening off, about 65 lbs. = 65×144 B.T.U. .... (If this water is utilized in diffusion this loss belongs to the diffusion dumpings.)	9,180	"	=14.7%
6. In the massecuites, first and second, total 20 lbs. (specific heat 0.5), cooled 126° F.	1,260 B.T.U.		= 2.0%
Total known losses	42,840 B.T.U.		=68.8%
Undetermined losses	18,860	"	=31.2%

APPENDIX III.

COMPARATIVE REVIEW OF THE STEAM AND COAL CONSUMPTION IN DIFFERENT SYSTEMS OF EVAPORATION AND HEATING.

In order to illustrate more fully the different evaporator systems and to show the way the vapors and steam are utilized in heating and pan boiling, the following synopsis has been made of the combinations most in use. Obviously to make proper comparison, all conditions except the arrangement of the evaporating plant and the method of steam distribution must be rigidly uniform, and these data are so set forth in the table. In such a presentation an accurate view of the working of the various evaporating systems can be obtained.

In the table, the quantities of heat which are taken for heating and boiling are placed under the appropriate symbol for each body. If live steam is taken the amount is given in a special column. The amount of exhaust is taken as 30 lbs., if no figure is given over those of the first effect.

Steam and Fuel Consumption.

Given: Raw juice, 115 lbs. Thin juice, 125 lbs.

Water to evaporate, 100 lbs.

Exhaust steam, 30 lbs. (with centralization and good engines, 20 lbs.).

Steam for heating: Raw-juice heater, I (RJ_1) =3 lbs. Raw-juice heater, II (RJ_2) =7 lbs. Diffusion (D) =8 lbs. Carbonatation (C) =7 lbs. Thin juice (tj) =4 lbs. Thick juice (TJ) =1 lb.

Steam for boiling the thickened juice, 11 lbs., for boiling sirup, 1 lb. Total $(B)=12$ lbs.

Special uses of steam: For power $=2$ lbs. for heating juice in evaporators $=3$ lbs. Cooling losses $=6$ lbs. Steam loss $=2$ lbs. Total $=13$ lbs.

Water evaporated in boilers: 8 lbs. per 1 lb. of coal.

Evaporator System.	Steam. Lbs.		Coal. Lbs.
	Evap.	Total.	
I II III $RJ_1=3$ $D=8$ $RJ_2=7$ $C=7$ $tj=4$ $TJ=1$ $B=12$	72.3	85.3	10.7
I II III $B=12$ $D=8$ $RJ_1=3$ $RJ_2=7$ $C=7$ $tj=4$ $TJ=1$	63.3	76.3	9.5
JH I II III $B=12$ $D=8$ $RJ_1=3$ $RJ_2=7$ $C=7$ $tj=4$ $TJ=1$	55.6	68.6	8.5
30 lbs. JH_{I} JH_{II} I II IV $B=4$ $B=8$ $D=8$ $RJ_1=3$ $tj=4$ $RJ_2=7$ $TJ=1$ $C=7$	51.7	64.8	8.1
20 lbs. JH_{I} JH_{II} I II III $B=4$ $B=8$ $D=8$ $RJ_1=3$ $tj=4$ $RJ_2=7$ $TJ=1$ $C=7$	47.8	60.8	7.6
I II III IV $RJ_1=3$ $D=8$ $RJ_2=7$ $C=7$ $tj=4$ $TJ=1$ $B=12$	64.0	77.0	9.6
I II III IV $D=8$ RJ_2-7 $RJ_1=3$ $B=12$ $C=7$ $tj=7$ $TJ=1$	59.3	72.3	9.0

Evaporator System.	Steam. Lbs.		Coal. Lbs.
	Evap.	Total.	
$B=12$ I II III IV $D=8$ $RJ_2=7$ $RJ_1=3$ $C=7$ $tj=4$ $TJ=1$	55.5	68.5	8.6
I II III IV $D=8$ $RJ_2=7$ $RJ_1=3$ $tj=7$ $C=7$ $TJ=1$ $B=12$	50.8	63.8	8.0
JK I II III IV $B=12$ $D=8$ $RJ_2=7$ $RJ_1=3$ $C=7$ $tj=4$ $TJ=1$	50.4	63.4	7.9
30 lbs. SK I II III IV $B_2=4$ $D=8$ $RJ_2=7$ $RJ_1=3$ $tj=4$ $C=7$ $TJ=1$ $B_2=8$	47.4	60.4	7.5
20 lbs. JH I II III IV $B_1=4$ $D=8$ $RJ_1=7$ $RJ_1=3$ $tj=4$ $C=7$ $TJ=1$ $B_1=8$	45.4	58.4	7.3
20 lbs. JH_{I} JH_{II} I II III IV $B_2=4$ $B_1=8$ $D=8$ $RJ_2=7$ $RJ_1=3$ $tj=4$ $C=7$ $TJ=1$	42.3	55.3	7.3
20 lbs. JH_{I} JH_{II} I II III IV $B_2=4$ $D=8$ $RJ_2=7$ $RJ_1=3$ $C=7$ $tj=4$ $TJ=1$ $B_1=8$	42.3	55.3	6.9
I II III IV V $tj=4$ $D=8$ $RJ_2=7$ $RJ_1=3$ $TJ=1$ $C=7$ $B=12$	45.4	58.4	7.3

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